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Journal and Proceedings, Royal Society of New South Wales, Vol. 97, p. 1–29, 1963

A Lower Carboniferous Fauna from Lewinsbrook, New South Wales

JOHN ROBERTS

*Department of Geology, University of New England, Armidale, N.S.W.**

ABSTRACT—An Upper Tournaisian fauna from the Bingleburra Formation, Lewinsbrook, N.S.W., is described, including three new genera—an auloporoid coral *Bibucia*, the brachiopod *Acuminothyris* and the trilobite *Conophillipsia*. Fourteen new species described are: *Bibucia tubiformis, Fenestella brownei, F. gresfordensis, F. wilsoni, Productina globosa, Pustula multispinata, Acuminothyris triangularis, Brachythyris elliptica, ? Delthyris papilionis, ? Thomasaria voiseyi, Cleiothyridina segmentata, C. squamosa, Streblochondria obsoleta,* and *Conophillipsia brevicaudata*. *Streptorhynchus spinigera* (McCoy) is redescribed. The palaeoecology and affinities of the fauna are discussed.

Introduction

The study of the palaeontology of the lowest Carboniferous beds in the Hunter Valley, New South Wales, has been almost entirely neglected since the last century. The present work is the first detailed examination of the Lewinsbrook fauna. The first worker to examine the fauna was McCoy (1847) who described *Orthis australis* McCoy, *Spirifer lata* McCoy, *Orthis striatula* Schlotheim, *Productus antiquatus* Sowerby and *Productus setosus* Phillips from material collected by the Rev. W. B. Clarke. Campbell (1957), who redescribed *Rhipidomella australis* (McCoy) and *Asyrinxia lata* (McCoy) on topotype material, has been the only other worker to collect from Lewinsbrook.

The Lewinsbrook localities are the lowest known fossil horizons in the Bingleburra Formation, the oldest formation exposed in the Gresford-Dungog district. The horizons do not crop out elsewhere in the region studied by the author; as a whole the fauna, on present-day knowledge, is unique in the Carboniferous of New South Wales.

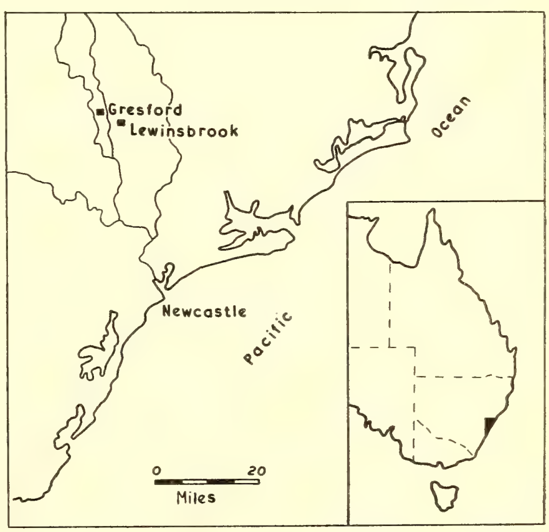
All locality numbers in the figures and text of this paper refer to The University of New England Collection. Grid references are from the Dungog 1 Mile Military Sheet. Specimen numbers, unless otherwise stated, refer to The University of New England Palaeontological Collection.

STRATIGRAPHY

Lewinsbrook is situated 2·5 miles south-east of the town of Gresford and approximately 40 miles north-east of Newcastle (Text-fig. 1). The geology of the Gresford district has been described in a previous paper (Roberts, 1961). Text-figure 2 illustrates the stratigraphic nomenclature of the formations described in this work. The following information is a brief summary of the stratigraphy of the Gresford district.

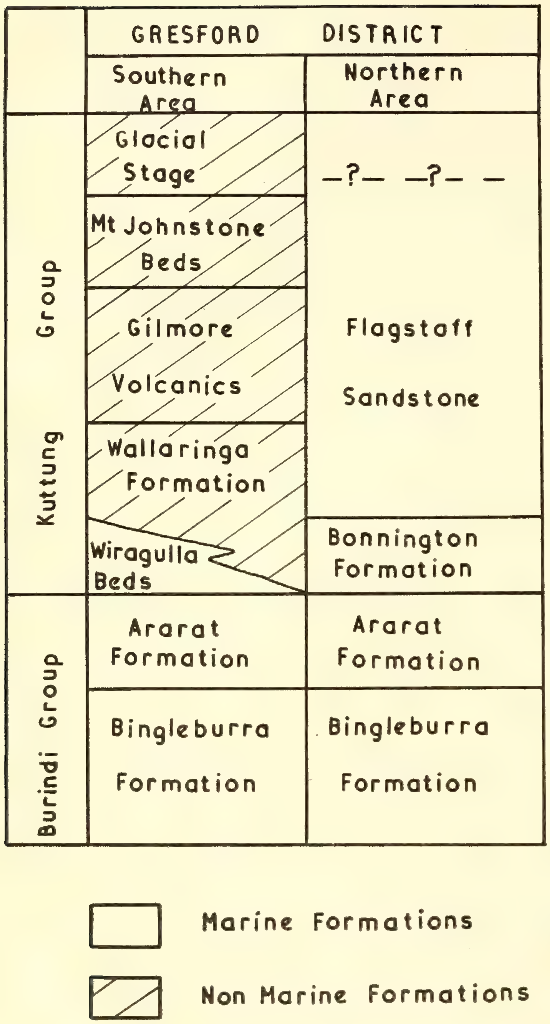
The Bingleburra Formation (approximately 3,000 feet in thickness) consists of mudstones, siltstones, oolitic and crinoidal limestones and interbedded sandstones and conglomerates and is overlain by the Ararat Formation (1,500 feet in thickness). This formation is composed of calcareous tuffaceous sandstones with minor mudstones and oolitic and crinoidal limestone lenses.

Following Ararat sedimentation marine conditions continued without interruption in the north of the area. The Bonnington Formation



TEXT-FIG. 1
Locality map.

* Present address: Geological Branch, Bureau of Mineral Resources, Canberra, A.C.T.



Text-fig. 2

Stratigraphic nomenclature of formations in the Gresford District.

(400 feet in thickness) consisting of siltstone and mudstone, underlies the coarse tuffaceous Flagstaff Sandstone (5,500+ feet in thickness).

To the south, following the deposition of the Ararat Formation, conditions changed in parts to a non-marine environment due to the uplift of a narrow belt stretching from Greenhills to Mt. Ararat (Roberts, 1961). Away from the influence of the uplift, for example at Wiragulla near Dungog, a thin marine mudstone and siltstone sequence (Wiragulla Beds) interfingers between the Ararat Formation and the non-marine Wallaringa Formation. The Wallaringa Formation (950 feet in thickness) comprises the Wallarobba Conglomerate Member and coarse tuffaceous sandstones. It is overlain by the Gilmore Volcanics, the Mt. Johnstone Beds (Sussmilch and David, 1920) and rocks of the Glacial " Stage " (Osborne, 1922).

Lewinsbrook Localities and Stratigraphic Section

The Lewinsbrook-Trevallyn fault block contains the majority of the important fossil horizons in the Gresford district and occurs in an area of considerable structural complexity to the east of the Camyr-Allyn fault. Text-figure 3 is a diagrammatic stratigraphic section showing lithologies and the stratigraphic relationships of the fossil localities. The L.50 and L.203 horizons have not been located in the Lewinsbrook-Trevallyn section, but are assigned to their present position on lithological and palaeontological grounds as their faunal composition is intermediate between that of the Lewinsbrook and Trevallyn horizons. This stratigraphic section differs from the type section of the Bingleburra Formation (Roberts, 1961) found seven miles to the north on the western limb of Lewinsbrook Syncline due to the bank-type oolitic limestone facies in the type area giving way southwards to a more clastic environment containing large conglomerate lenses.

The Lewinsbrook fossil localities in superpositional order are :

L. 86	.. ..	46059883
L.217	.. ..	46069882
L.216	.. ..	46079882
L.215	.. ..	46089882

L.215 is characterized by a rich assemblage of *Schizophoria* cf. *resupinata* (Martin) in a closely jointed grey siltstone.

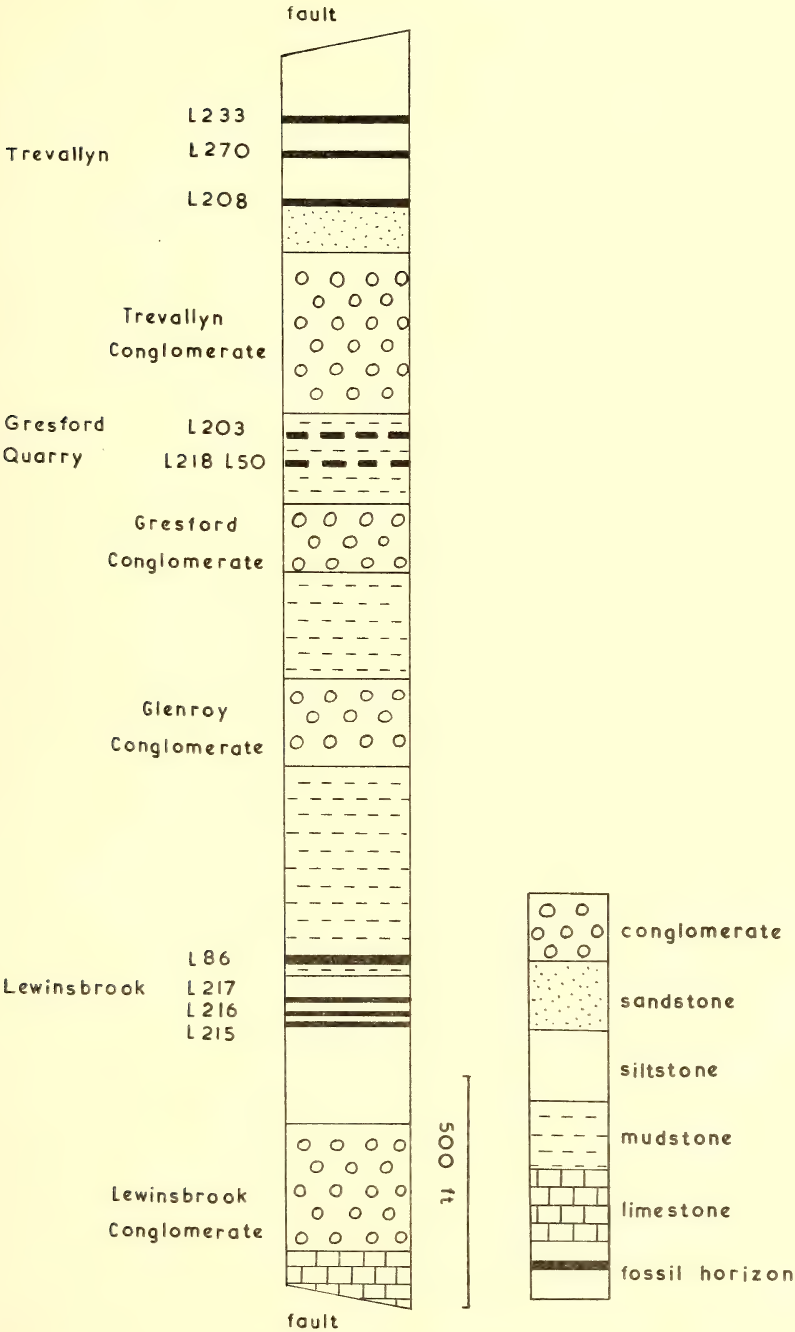
L.216, approximately 15 feet above L.215, is in a dark grey siltstone containing abundant *Rhipidomella australis* (McCoy).

L.217, a spiriferoid horizon, three to four feet above L.216, contains *Asyrinxia lata* (McCoy), *Brachythyris elliptica* n.sp. and *Acuminothyris triangularis* n.sp. in a dark grey siltstone.

L.86, approximately 20 feet above L.217, contains crowded fragments of polyzoa and small brachiopods in a pale brown mudstone.

The Fauna of the Lewinsbrook Localities

The following faunal list contains all identifiable forms collected from Lewinsbrook during the current investigation. The author has spent a total time of approximately one week collecting at Lewinsbrook and holds the opinion



TEXT-FIG. 3

Diagrammatic stratigraphic column of the Bingleburra Formation, Lewinsbrook-Trevallyn fault-block, showing lithologies and fossil horizons. For the sake of clarity the separation of fossil horizons is exaggerated.

that this list is likely to represent at least 85 per cent of the total fauna. Forms described in the text are distinguished by an asterisk.

The following species are common to all four localities :

***Fistulamina inornata* Crockford
***Goniocladia laxa* (de Koninck)
Rhipidomella australis (McCoy)
Schizophoria cf. *resupinata* (Martin)
Eomarginifera cf. *paradoxus* (Campbell)
Leptagonia cf. *analoga* (Phillips)
***Brachythyris elliptica* n. sp.
Unispirifer striatoconvolutus (Benson and Dun).

L.86 Fauna

**Bibucia tubiformis* n. gen. and sp.
**Cladochonus tenuicollis* (McCoy)
**Cladochonus* sp.
Streblotrypa parallella Crockford
Ramipora sp.
**Ptilopora konincki* Crockford
**Fenestella brownei* n. sp.
**Fenestella gresfordensis* n. sp.
**Fenestella wilsoni* n. sp.
Orbiculoidea sp.
Lingula sp.
Schuchertella sp.
**Streptorhynchus spinigera* (McCoy)
**Pustula multispinata* n. sp.
**Productina globosa* n. sp.
Marginatia sp.
Fluctuaria sp.
**Acuminothyris triangularis* n. gen. and sp.
**Cleiothyridina segmentata* n. sp.
**Cleiothyridina squamosa* n. sp.
Cleiothyridina sp.
Athyris sp.
**? Delthyris papilionis* n. sp.
Asyrinxia lata (McCoy)
**? Thomasaria voiseyi* n. sp.
Kitakamithyris sp.
Ptychospira sp.
Dielasma sp.
*" *Camarotoechia* " sp. A.
Stenoscisma sp.
? Girtypecten sp.
**Streblochondria obsoleta* n. sp.
**Conophillipsia brevicaudata* n. gen. and sp.

L.217 Fauna

Krotovia sp.
**Productina globosa* n. sp.
**Acuminothyris triangularis* n. gen. and sp.
Dielasma sp.
Athyris sp.
Asyrinxia lata (McCoy).

L.216 Fauna

Orbiculoidea sp.

L.215 Fauna

**Cladochonus tenuicollis* (McCoy)
**Cladochonus* sp.
Ramipora bifurcata Crockford
Streblotrypa parallella Crockford
Krotovia sp.
**Cleiothyridina squamosa* n. sp.
**Acuminothyris triangularis* n. gen. and sp.
**? Thomasaria voiseyi* n. sp.

For local correlation it is significant to note that the following species are restricted to the Lewinsbrook horizons :

Bibucia tubiformis n. gen. and sp.
Fenestella brownei n. sp.
Fenestella gresfordensis n. sp.
Fenestella wilsoni n. sp.
Pustula multispinata n. sp.
? Thomasaria voiseyi n. sp.
Conophillipsia brevicaudata n. gen. and sp.
Streblochondria obsoleta n. sp.

Productina globosa n. sp and *? Delthyris papilionis* n. sp. occur in the Lewinsbrook and L.50 Gresford Quarry horizons and *Acuminothyris triangularis* n. gen. and sp. is recorded from Lewinsbrook, L.50 Gresford Quarry and L.233 Trevallyn. Most other forms appear to be longer ranging.

Type of Preservation

Most of the specimens are preserved as internal and external moulds, the fine-grained sediment infilling the finest features of the shell ornament and even the zooecia of polyzoa. Original shell material still remains in the unweathered portions of the L.215–L.217 localities.

Palaeoecology

From a study of the faunal lists it is obvious that the L.215–L.217 localities do not have as diverse a fauna as L.86. These three localities all occur in bedded siltstone.

The following points relevant to the palaeoecology have been noted in the three lower localities (L.215–L.217). They are by no means conclusive because of the restricted outcrops.

(1) The long spines of *Eomarginifera* cf. *paradoxus* (Campbell) frequently remain unbroken, indicating a quiet environment.

(2) Pedicle valves of *Schizophoria* cf. *resupinata* (Martin) are generally oriented in a lower or ventral position.

(3) A common position of *Acuminothyris triangularis* in the L.217 locality is with its hinge line lying flat on the bedding plane of the sediment, apparently in its living position.

(4) Fragmentary material is relatively uncommon and is restricted to minor crinoidal debris associated with L.215.

(5) Fragmentary worm burrows penetrate much of the siltstone.

The above evidence suggests that the shells may be in approximate positions of growth, that current activity was minimal, and that the bottom sediment was apparently a suitable habitat.

L.86, with a richer and more diverse fauna, shows more satisfactory evidence regarding the conditions existing during its accumulation.

(1) Many brachiopod shells are dissociated, presumably as a result of current action.

(2) The great majority had been killed by a boring organism, probably a predatory gastropod, which bored vertically through the shell into their adductor muscles (see Pl. 3, fig. 7*a*, *Streptorhynchus spinigera* McCoy).

(3) Fenestrate polyzoa and *Goniocladia* are usually broken, have fragmentary margins, and lie flat on the bedding planes.

(4) All productids, including the common genera *Productina, Pustula* and *Eomarginifera,* have broken spines.

(5) Many shells are distorted, probably due to compaction of sediment during lithification.

(6) There is a large amount of fragmentary material, particularly disarticulated crinoid stems and plates, polyzoa and tabulate coral debris.

As most shells are not worn, it appears that the fauna had been transported a short distance before burial. The muddy conditions existing during the deposition of the sediment at L.86 would not, in my opinion, have provided a suitable bottom environment for such a rich fauna, as clear water would have been essential for the growth of the polyzoan and coelenterate members of the assemblage. The mass of fragmentary material indicates substantial current activity at the time of deposition.

The Age of the Fauna

The Lewinsbrook fauna is dated as Upper Tournaisian. Two distinctive species from this fauna, *Productina globosa* and *? Thomasaria* cf. *voiseyi,* have been collected from the Werrie Basin, N.S.W., where they occur in association with an Upper Tournaisian (probably Cu II_{α}) goniatite fauna at the base of the Merlewood Section (Delépine, 1941 ; Campbell and Engel, in press). The Upper Tournaisian age is supported by the following evidence.

Productina globosa morphologically resembles *P. sampsoni* (Weller) from the Fern Glen Formation, Missouri ; the Caballero and Lake Valley Formations, New Mexico ; the Rockford Formation, Indiana ; and the Kinderhook of Iowa (Muir-Wood and Cooper, 1960). The Chouteau Limestone and its equivalents, for example the Rockford Limestone, have been dated as Upper Tournaisian (Cu II_{α}) by Voges (1960) and Collinson *et al.* (1962). The latter workers considered the Fern Glen Formation to be Lower Viséan (probably Cu II_{β}) in age. It is also highly significant that the Upper Tournaisian goniatite assemblage from the Rockford and Chouteau Limestones is very close to that from the lower parts of the Carboniferous sequence in the Werrie Basin (Miller and Collinson, 1951) from where this species has been collected.

Brachythyris elliptica is morphologically close to *B. pinguis* (Sowerby) which occurs in the Viséan of Great Britain and in the Upper Tournaisian (Tn_{3b}) and Lower Viséan in Belgium.

The trilobite *Conophillipsia brevicaudata* suggests a slightly older age because of its morphological similarity with *C. labrosa* (Weber) and *C. kazakensis* var. *paucicostata* (Weber). The latter species occur in the Lower Tournaisian Kassin Beds and possibly in the Transition Beds of the Kirgiz Steppe of Russia (Weber, 1937).

The general form of the colonies and the arrangement of the branches and fenestrules of the fenestrate polyzoa, viz. *Fenestella brownei* and *F. wilsoni,* resemble certain members of the fauna described by Koenig (1958) from the Chouteau Group of Central Missouri.

Relationship to other Faunas

As previously mentioned, the fauna from the base of the Namoi Formation in the Werrie Basin, N.S.W., contains two diagnostic species, *Productina globosa* and *? Thomasaria* cf. *voiseyi,* in common with the Lewinsbrook fauna. These species occur in mudstones of the Namoi Formation at Keepit Dam on the Namoi River, approximately 500 feet above the Rangari Limestone, and on a comparable horizon in the Merlewood Section.

The Lower Carboniferous fauna described by Maxwell (1954) from Mt. Morgan, Queensland, approximately 1,000 miles north of the Gresford

district, contains two distinctive species which may be related morphologically with forms in the Lewinsbrook fauna. The species *Dimegelasma kennedyense* may be close to that referred to ? *Thomasaria voiseyi*, and *Brachythyris* cf. *pinguis* (Sowerby) is possibly similar to *B. elliptica*. Closer comparison is hampered by the poor preservation of the Queensland specimens. *Schizophoria* cf. *resupinata* (Martin) and *Leptagonia* cf. *analoga* (Phillips) are common to both faunas.

Closest general relations with overseas faunas appear to be with the Kinderhook of America, where *Leptagonia analoga* (Phillips) resembles *L.* cf. *analoga* (Phillips), *Schizophoria posttriatula* Weller is similar to *S.* cf. *resupinata* (Martin) and *Productina sampsoni* (Weller) resembles *P. globosa*.

Tournaisian faunas from the Moscow Basin (Sarycheva and Sokolskaya, 1952), the Donetz Basin (Rotai, 1931) and the Kousnetzk Vasin (Tolmachoff, 1924) have no similarities with the Lewinsbrook fauna except for very common forms such as *Leptagonia analoga* (Phillips).

Morphologically related species in the European Lower Carboniferous are, in general, long ranging and cannot indicate a precise age. *Unispirifer striatoconvolutus* Benson and Dun is closely related morphologically to *Spirifer tornacensis* de Koninck, which ranges throughout most of the Tournaisian. *Schizophoria* cf. *resupinata* (Martin) and *Leptogonia* cf. *analoga* (Phillips) are virtually indistinguishable from the European species and *Rhipidomella australis* (McCoy) is considered by Campbell (1957) to be very close to *R. michelini* (L'Eveillé). In Europe, *S. resupinata*, *L. analoga* and *R. michelini* range throughout the Dinantian.

Acknowledgments

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SYSTEMATIC PALAEONTOLOGY

Coelenterata

Order TABULATA Milne Edwards and Haime 1850

Family AULOPORIDAE Milne Edwards and Haime 1851

Genus Bibucia n. gen.

Type Species: *Bibucia tubiformis* n. sp.

Diagnosis: Biserial stem-like colony with two separate, opposing, alternating rows of corallites connected by mural pores; trumpet-shaped corallites bud from the distal portion of the parent corallite; branches occur at irregular intervals and arise from a second bud on proximal portions of parent corallite; epithecal tissue between corallites probably lamellar calcite.

Remarks: The only auloporoid resembling this genus is the North American Silurian genus *Bainbridgia* Ball and Grove (in Hill and Stumm, 1956, p. F470, fig. 355, 11*a*–*b*). The corallites of *Bainbridgia* are not connected by mural pores and have a different shape from those in *Bibucia*.

The name *Bibucia* is taken from the Latin "*bucina*", a trumpet, and refers to the two rows of trumpet-shaped corallites.

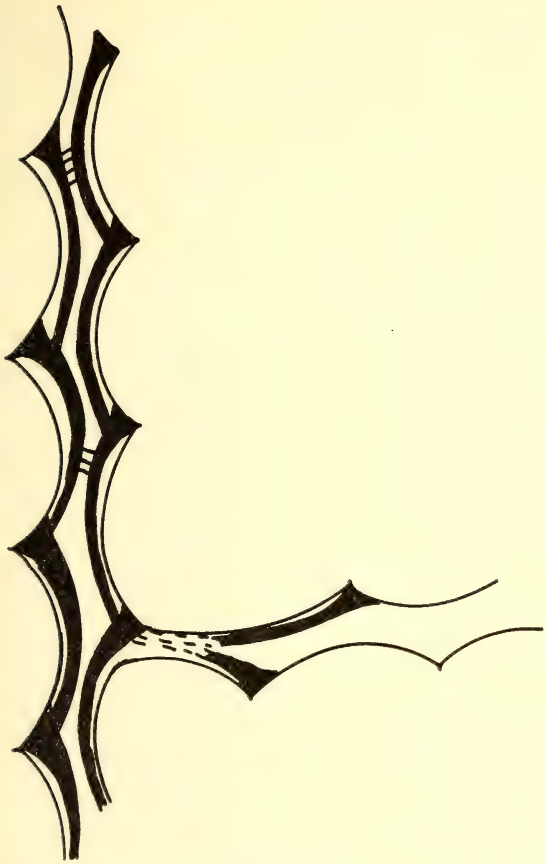
Bibucia tubiformis n. sp.

Plate 3, figs. 8–9

Diagnosis: Branches always arise from immediately beneath an aperture; corallites elongate, trumpet-shaped; apertures 0·4 mm. in diameter, with small lip-like projections; they are inclined at approximately 30° to the main stem; distance between apertures 2–2·5 mm.

Description: The colony consists of a main biserial stem giving rise to unconnected, slightly inclined biserial branches at irregular intervals; the colony is probably an erect ramose structure with branches arranged both in the same plane as the corallites and also possibly at 90° to this; one broken branch normal to the plane of the corallites has been observed. The exterior is smooth and devoid of ornament.

Alternating corallites are arranged in two separate opposing rows on either side of the stem; corallites increase by budding from immediately below the calice on the distal portion of the parent corallite. Corallites are



TEXT-FIG. 4

Bibucia tubiformis n. sp. ($\times 9\frac{1}{2}$), showing the shape of the corallites (black) and mural pores. The system of budding of the corallites at branching is obscure. This diagram was constructed from the specimen in fig. 9, Plate 3.

thin, elongate, trumpet-shaped, tubular for nearly three-quarters of their length and then expand towards the aperture. The apertures are round, inclined at approximately 30° to the main stem and have a small lip-like projection on their proximal margins. The diameter of the apertures is 0·4 mm. and the distance between the apertures (on same side of colony) 2–2·5 mm. The arrangement of tabulae in the corallites is unknown. Mural pores occur immediately below the calice of one corallite and on the mid-portion of the other and link the two rows (Text-fig. 4).

Branching takes place from the proximal portion of a corallite by the formation of two buds. The new branch always arises from immediately beneath an aperture.

REMARKS: The author knows of no other species comparable with *Bibucia tubiformis*. Text-figure 4 was constructed from a specimen having infilled zooecia and the sclerenchyma dissolved.

The specific name *tubiformis* refers to the trumpet-shaped corallites.

OCCURRENCE: This genus and species is known only from L.86 Lewinsbrook.

MATERIAL: F.5366–F.5372. *Holotype* F.5366, *paratype* F.5370.

Genus CLADOCHONUS McCoy 1847

TYPE SPECIES: *Cladochonus tenuicollis* McCoy, 1847, Ann. Mag. Nat. Hist. 20, p. 227, pl. 11, fig. 8.

DIAGNOSIS: See Hill and Stumm (1956, p. F472).

Cladochonus tenuicollis McCoy

Plate 1, fig. 4

REMARKS: *C. tenuicollis* has been revised by Hill and Smyth (1938). This material differs from the type specimens (Hill and Smyth, pl. 23, fig. 1) insofar as the distal portion of the calice in front of the branch on each corallite is shorter.

To the best of my knowledge this is the first description and illustration of a reptant ring of *Cladochonus tenuicollis*.

Four proximal corallites forming the reptant ring are compressed and much shorter than those on the branches; each proximal corallite gives rise to a major branch of the colony.

MEASUREMENTS (in mm.):

Branching Corallites

Length	Width	
	Proximal	Rim of calice
12–13	2·5–2·7	5

Proximal ring corallites

Length	Width	
	Proximal	Rim of calice
9–10	2·5	5

OCCURRENCE: This species occurs at L.215 and L.86 Lewinsbrook, L.50 Gresford Quarry and L.233 Trevallyn.

MATERIAL: F.5374.

Cladochonus sp.

Plate 1, figs. 1–3

DESCRIPTION: The shape of the colony is unknown. Corallites are small, long, slender and trumpet-shaped; they are 0·3–0·7 mm. in diameter in their proximal portions, expanding to 1·5–2·2 mm. at the calice rim. Length of the corallites ranges from 6–12 mm. Corallite stems curve slightly towards the axis of the

colony and then swing abruptly outwards towards the distal regions, so that the apertures are often at 70°–80° to the axis of the stem. The calice of each corallite often projects up to 2·5 mm. in front of the bud of the succeeding corallite. Apertures are round. No traces of septal spines have been observed. Thickness of the external walls of the corallites is slightly less than 0·1 mm. in distal and proximal regions. Corallites are ornamented only by growth annulations.

Two branches, not always in one plane, may arise from variable positions on one corallite. The two buds may arise one behind the other on the upper surface of the parent corallite, or the second bud may branch from the front of the parent corallite.

Measurements (in mm.) :

Length of corallite	Width of corallite	
	Proximal	Rim of calice
12·0	0·6	2·0
11·0	0·6	2·2
10·5	0·6	1·75
10·0	0·5	1·5
10·0	0·7	1·8
9·5	0·5	1·8
6·0	0·5	2·0
6·0	0·3	—

Remarks : The corallites of this material are longer and more slender than those of *C. crassus* McCoy. *C.* sp. is far more delicate than *C. tenuicollis* McCoy and in size is intermediate between *C. crassus* and *C. tenuicollis*.

Occurrence : This species is known from L.215 and L.86 Lewinsbrook.

Material : F.5755–F.5766.

The following three polyzoan species described by Crockford (1947) are refigured because of the inadequacy of the original photographs.

Polyzoa

Order CYCLOSTOMATA Bush 1852
Family HEXAGONELLIDAE Crockford 1947
Genus Fistulamina Crockford 1947

Type species : *Fistulamina inornata* Crockford, 1947.

Diagnosis : See Crockford (1947, p. 28–29).

Fistulamina inornata Crockford
Plate 1, fig. 5

Fistulamina inornata Crockford, 1947, Proc. Linn. Soc. N.S.W., 72, p. 29, pl. 4, figs. 5–6.

Remarks : Several additions can be made to Crockford's description of the species.

(1) Fine longitudinal ridges occur between the apertures on occasional specimens.
(2) The outer rim of the apertures is raised into hooded lunaria which are visible only on well preserved specimens.
(3) The number of rows of zooecial apertures is more variable than previously realized ; in the Lewinsbrook material the number ranges from 5–10.

Occurrence : This species occurs at L.215–L.217, L.86 Lewinsbrook and L.50 Gresford Quarry.

Material : F.5361–F.5363.

Family GONIOCLADIIDAE Nikiforova 1938
Genus Goniocladia Etheridge 1876

Type species : *Goniocladia cellulifera* Etheridge, 1876, Geol. Mag., 2, p. 522–523.

Diagnosis : See Bassler (1953, p. G89–90).

Goniocladia laxa (de Koninck)
Plate 1, figs. 6–8

Goniocladia laxa (de Koninck), Crockford, 1947, Proc. Linn. Soc. N.S.W. 72, p. 29–31, pl. 5, figs. 3–5.

Occurrence : *Goniocladia laxa* occurs at L.215–L.217, L.86 Lewinsbrook, L.50 Gresford Quarry and L.233 Trevallyn.

Material : F.5353–F.5360.

Order CRYPTOSTOMATA Vine 1833
Family ACANTHOCLADIIDAE Zittel 1880
Genus Ptilopora McCoy 1845

Type species : *Ptilopora pluma* McCoy, 1845.

Diagnosis : See Bassler (1953, p. G128).

Ptilopora konincki Crockford
Plate 2, figs. 1–2

Ptilopora konincki Crockford, Proc. Linn. Soc. N.S.W. 72, p. 39–41, pl. 6, fig. 5.

Occurrence : *Ptilopora konincki* occurs at L.86 Lewinsbrook and at stratigraphically higher localities listed in Crockford (1947).

Material : F.5364–F.5365.

Family FENESTELLIDAE King 1850
Genus Fenestella Lonsdale 1839

Type species : *Fenestella subantiqua* d'Orbigny.

Diagnosis : See Bassler (1953, p. G120).

Fenestella brownei n. sp.
Plate 2, figs. 3–5

Diagnosis : Moderately coarse mesh ; branches thin, bearing a broad smooth carina ; fenestrules

large and irregularly rectangular ; 5–9 apertures per fenestrule ; delicate carina on dissepiments ; at bifurcation a zooecial aperture is always situated on the inner part of the fork of the bifurcation ; reverse surface smooth.

DESCRIPTION : Fragments described are from the lower mid-area of the zoarium.

Branches are thin, 0·30–0·38 mm. in width and moderately straight ; 13–15 branches occur in 10 mm. The branch expands slightly before bifurcation. A broad carina separates the two rows of zooecial apertures. A third aperture is always present in the fork of the bifurcation. Apertures are small, round, surrounded by a distinct peristome and are slightly elevated above the branch and inclined towards the top of the zoarium. The aperture plus peristome has a diameter of 0·1 mm. There are 17–18 apertures per 5 mm., and 5–9 apertures per fenestrule, averaging 7.

Zooecia alternate and have a regular, elongate, ovoid shape. Fenestrules are irregularly rectangular, often having rounded or sharply pointed extremities ; the latter occurs near the bifurcation of the branches. Fenestrules range from 0·4–0·5 mm. in width (at their mid-length) and from 1·8–3·0 mm. in length, averaging about 2 mm. There are 4–5 fenestrules per 10 mm.

Dissepiments are below the level of the obverse surface and bear a thinner keel than that on the branches ; dissepiments have an average width of 0·2–0·3 mm. The reverse side of the colony is completely smooth and rounded.

REMARKS : In general appearance and overall dimensions this species resembles *F. propinqua* de Koninck (Crockford, 1947, p. 35–36, pl. 6, fig. 4), but differs in possessing a broad carina on the branches, a thinner more delicate carina on the dissepiments and in having the third zooecial aperture (at bifurcation) always situated in the fork of the bifurcation.

Fenestella oblongata Koenig (1958, p. 132–134, pl. 21, fig. 4, text-figs. 1*e, f*) resembles *F. brownei* in the general shape of the colony, branches and fenestrules. However, *F. brownei* has a much wider keel on the branches, a smaller keel on the dissepiments and a smooth reverse surface.

The name is given to honour Dr. W. R. Browne, formerly of the University of Sydney.

OCCURRENCE : *F. brownei* is known only from L.86 Lewinsbrook.

MATERIAL : F.5346–F.5352. *Holotype* F.5346, *paratypes* F.5347, F.5348.

Fenestella gresfordensis n. sp.

Plate 2, figs. 6–8

DIAGNOSIS : Fine mesh, thin branches ; regularly rectangular fenestrules, with 6 apertures per fenestrule ; carina with single row of nodes at spacings of 0·4 mm. ; aperture present at either end of dissepiment ; apertures round and slightly hooded ; branches with striate reverse surface.

DESCRIPTION : The material is fragmentary. Measurements are from the older portions of the colony. Branches are thin, 0·15–0·30 mm. in width and have an even bifurcation. There are 17–18 branches per 10 mm. The carina is moderately developed, broadly rounded and bears small sharply pointed nodes every 0·4 mm. The nodes have a density of 6 per fenestrule, plus 1 on the dissepiment. Apertures are small, round and alternating ; they are generally less than 0·1 mm. in diameter and have a very small peristome which is hooded on the distal portion so that the aperture faces the older portion of the colony. In most cases, two slightly larger apertures, of diameter 0·12 mm., are found on either side of the dissepiments at their junction with the branches. The number of apertures per fenestrule ranges from 5–6, with an average of 6, plus 1 on the dissepiment. There are approximately 20–24 apertures per 5 mm. Three apertures usually occur immediately before bifurcation. Fenestrules are sharply rectangular and regularly developed. Width of the fenestrules varies from 0·2–0·5 mm. and their length ranges from 1–2·3 mm., averaging 1·5 mm. There are 5–7 fenestrules per 10 mm. Dissepiments are short, measuring 0·1–1·15 mm. They are situated slightly below the level of the branch, are acarinate, narrow on their reverse surface and slightly higher than the base of the branches. Zooecia are alternately arranged and irregularly triangular in shape ; the apex of the triangle, at the apertures, is rounded, while the base of the zooecium is expanded into a flange. The reverse surface of each branch is finely ornamented by 4–6 high ridge-like striae.

REMARKS : No species comparable with *F. gresfordensis* have been described from the Carboniferous of Australia.

Fenestella plebia McCoy, described by Whidborne (1898, pl. 22, figs. 14–15, pl. 23, fig. 1) from the Pilton Beds of England is, as far as can be determined, similar to *F. gresfordensis*, but differs in the absence of larger apertures on the dissepiments.

This species has been named after the town of Gresford, N.S.W.

Occurrence : *F. gresfordensis* is known only from L.86 Lewinsbrook.

Material : F.5335–F.5339, F.5345. *Holotype* F.5335, *paratypes* F.5336, F.5338.

Fenestella wilsoni n. sp.
Plate 3, figs. 10–12

Diagnosis : Fine mesh ; branches thin ; fenestrules rectangular ; 3–4 apertures per fenestrule ; obsolete carina bears 3 nodes per fenestrule plus 1 on the dissepiment ; zooecia triangular ; branches with striate reverse surface.

Description : The material is fragmentary. Measurements are taken from the older portions of the colony. Branches are straight, narrow, 0·15–0·2 mm. in width and have a very distant bifurcation. There are 23–24 branches per 10 mm. The carina is low, obsolete and bears small nodes with a density of 3 per fenestrule, plus 1 on the dissepiment. Apertures are small, circular, 0·07 mm. in diameter, barely raised above the level of the branch and are surrounded by minute peristomes. There are 3–4 (usually 4) zooecial apertures per fenestrule. Fenestrules are sharply rectangular to slightly oval and elongate. Their width ranges from 0·2–0·3 mm. and length averages 0·8 mm., ranging from 0·7–1 mm. There are 12–13 fenestrules per 10 mm. Dissepiments are short, measuring 0·07–0·1 mm., and are lower than the branches on both the obverse and reverse surfaces. Zooecia are triangular on the reverse surface of the colony. The reverse surface of the branches is ornamented with 5–6 fine raised striae.

Remarks : *F. wilsoni* differs from *F. acarinata* Crockford (1947, p. 36, pl. 6, fig. 3) in possessing a node-bearing carina, sharply rectangular fenestrules, dissepiments which are below the level of both the obverse and reverse surfaces and round apertures, barely raised above the surface of the branch.

F. wilsoni differs from *F. serrulata* Ulrich, figured by Koenig (1958, pl. 21, fig. 5, text-fig. 1*m*, *n*), in the possession of one more aperture per fenestrule and slightly wider fenestrules.

This species is named after Mr. C. H. Wilson, " Brinkburn ", Gresford.

Occurrence : *F. wilsoni* is known only from L.86 Lewinsbrook.

Material : F.5340–F.5345. *Holotype* F.5340 *paratypes* F.5341–F.5342.

The three species of *Fenestella* described above have their measurements summarized in the following table. They are readily distinguished by the shape of the zooecial infillings.

Measurements (in mm.) on Fenestella

	Branches		Dis-sepiments	Fenestrules			Apertures			Nodes	Zooecia
	Width	Number in 10 mm.	Width	Width	Length	Number in 10 mm.	Diameter across Crest of Peristome	Number/ Fenestrule	Number/ 5 mm.	Number/ Fenestrule	Shape
Fenestella brownei (F.5346)	0·3–0·38	13–15	0·2 –0·3	0·4–0·5	1·8–3·0	4–5	0·1	5–9	17–18	—	ovoid
Fenestella gresfordensis (F.5335)	0·15–0·30	17–18	0·1 –0·15	0·2–0·5	1·0–2·3	5–7	0·1	5–6+1 on dis-sepiment	20–24	6+1 on dis-sepiment	triangular with flange
Fenestella wilsoni (F.5340)	0·15–0·2	23–24	0·07–0·1	0·2–0·3	0·7–1·0	12–13	0·07	3–4	not measured	3+1 on dis-sepiment	triangular

Brachiopoda

Suborder STROPHOMENOIDEA Maillieux 1932

Superfamily ORTHOTETACEA Williams 1953 emend. Stehli 1954

Family SCHUCHERTELLIDAE Stehli 1954

Subfamily STREPTORHYNCHINAE Stehli 1954 emend. Thomas 1958

Genus STREPTORHYNCHUS King 1850

TYPE SPECIES: *Terebratulites pelargonatus* Schlotheim, 1816.

DIAGNOSIS: See Thomas (1958, p. 38).

Streptorhynchus spinigera (McCoy)
Plate 3, figs. 4–7

Orthis spinigera (McCoy), 1847, Ann. Mag. Nat. Hist., 20, p. 235, pl. 13, fig. 3.

DIAGNOSIS: Shell biconvex, wider than long; pedicle valve with long umbo and very narrow delthyrium; brachial valve convex anteriorly; coarse costae in 3 ranks, crossed by thick lamellar flanges, giving rise to spinose projections; large divergent socket plates and strong median septum in brachial valve.

DESCRIPTION: External. The shell is small for the genus, biconvex, wider than long, subelliptical and has angular cardinal extremities.

Pedicle valve is gently convex and highest at the umbo. The beak is straight, elongate and extends behind the hinge, but does not overhang the cardinal area. The umbo may be distorted due to attachment of the valve. The hinge-line is straight and slightly shorter than the median width of the valve. A sinus is absent. The cardinal area is long, concave and set at an obtuse angle to the plane of the commissure. It is differentiated into primary and secondary regions by a groove running from the apex to a point mid-way between the delthyrium and the cardinal extremities and ornamented with horizontal growth lines. The inner secondary area has additional faint vertical striations. The narrow delthyrium is longer than wide and is covered by a strongly arched pseudodeltidium. Costae are poorly defined on the umbo.

Brachial valve is most strongly convex towards the anterior margin and except for a small umbonal convexity the posterior region along the hinge is almost flat. The cardinal area is narrow. The notothyrium is broader than long; it is covered by a convex chilidium of 3 overlapping lamellar plates which project posteriorly from the area and are divided by a small central indentation. A fold is absent. Costae are coarse and less well defined towards the hinge-line; they are arranged in three orders, increasing by regular intercalation. Measured on a valve 12 mm. wide and 8 mm. long, at 3 mm. from the umbo there are 7 primary costae per 3 mm.; at 6 mm. from the umbo—4 primary costae and 3 secondary costae per 3 mm.; at the anterior margin—2 primary costae, 3 secondary costae and 5 tertiary costae per 3 mm. A variable number of strong laminar flanges form blunt spinose projections, especially from the primary costae.

Internal. Pedicle valve. Diductor muscle scars are elongate, usually poorly defined, occur high on the umbo and may be moderately impressed into the shell. Adductor muscle scars are situated on a short posteriorly pointed median ridge. Where pedicle valves are distorted the median ridge and diductor muscle scars are poorly defined. Large teeth occur as thickenings on the sides of the delthyrium. Margins of the valve are marked with impressions of the external ornament.

Brachial valve. Adductor muscle scars are flabellate, pointed at the umbo, broaden anteriorly and are faintly marked by widely spaced longitudinal striae. The median septum becomes higher anteriorly and extends for one-third the length of the valve. Strong socket plates curve inwards posteriorly and join at the cardinal process. They diverge at approximately 90° and are produced past the sockets forming blunt crural bases. Sockets are rounded, well developed and laterally they flare widely. The cardinal process is large and bilobed, with the external lobes separated by a broad groove containing a sharp median projection near its dorsal surface; each lobe is subdivided by a median channel.

MEASUREMENTS (in mm.):

Pedicle valve

Length	Width	Hinge Width
11	14	8
7	6	—

Brachial valve

Length	Width	Hinge Width	Muscle Field Length	Muscle Field Width
12 est.	17	12	—	—
11·5	14	11	4	6
9·5	15	13	—	—
9	10·5	8	3	4
8	10	8	3	3
8	9	7	4	4

REMARKS: *S. spinigera* (McCoy) bears some resemblance to *S. minutum* Cummings, described by Weller (1914, p. 70–71, pl. 6, figs. 16–21), from the Salem Limestone, Mississippi Valley, U.S.A. However, *S. spinigera* is larger, has a

longer cardinal area, a narrower delthyrium and the pedicle valve does not become concave anteriorly. The brachial valve is almost flat at the umbo and the costae do not bifurcate.

As far as can be ascertained no other comparable species of *Streptorhynchus* have been described.

Occurrence : This species occurs at L.86 Lewinsbrook, L.53 Greenhills and L.233 Trevallyn.

Despite an exhaustive search, the type locality of *S. spinigera* (McCoy) at Dunvegan on the Paterson River, N.S.W., cannot be found. This is probably due to a change in the course of the Paterson River since the last century, when the Rev. W. B. Clarke collected a large fauna from Dunvegan.

Material : F.5250–F.5261.

Suborder PRODUCTOIDEA Maillieux 1940
Superfamily PRODUCTACEA Waagen 1883
Family LEIOPRODUCTIDAE Muir-Wood and Cooper 1960
Subfamily PRODUCTININAE Muir-Wood and Cooper 1960
Genus Productina Sutton 1938 emend. Muir-Wood and Cooper 1960

Type species : *Productus sampsoni* Weller 1909, Bull. Geol. Soc. Amer., 20, p. 300, pl. 12, figs. 18–22.

Remarks : Muir-Wood and Cooper (1960) using hypotype material have emended this genus to include forms having an essentially lamellose brachial exterior. Previously, Sutton (1938, p. 551) noted that the brachial valve was costate, while Weller (1914, p. 130) in describing *Productus sampsoni*, the type species of *Productina*, recorded a brachial valve " marked by radiating costae similar to those of the opposite valve, and also by similar concentric laminae ". This material bears a closer resemblance to the revised diagnosis than to Sutton's original description of the genus. Since hypotype material has been used in its revision, the new concept of the genus is valid. The Lewinsbrook specimens are included in *Productina* Sutton, emend. Muir-Wood and Cooper on the basis of ornament, shape and the morphology of the brachial valve (Text-fig. 5). The latter differs from the type species only in the strength of the lateral ridges and in the geniculate anterior margin of the brachial valve.

Avonia Thomas (1914) is distinguished from this material by its weaker costae, which develop only in older individuals, and in the more spinose nature of the pedicle valve.

Productellina Reed (1943) is regarded as a " nomen dubium " as the type specimen is unidentifiable and thus cannot be compared with this material.

Productina globosa n. sp.
Plate 3, figs. 1–3

Diagnosis : Strongly convex pedicle valve with 8–9 costae per 3 mm. at anterior margin : cardinal margins with one spine near umbo and another at lateral extremities ; 6–8 spines in poorly defined band well down on the trail ; brachial valve uniformly concave, ornamented with overlapping concentric lamellae and obsolete costellae ; brachial adductor muscle scars on two high platforms are separated by a median ridge which broadens anteriorly ; lateral ridges weak.

Description : External. The shell is concavo-convex and globular.

Pedicle valve is strongly convex, with the greatest convexity immediately behind the mid-line. The shoulders are steep and the cardinal extremities flat. Greatest width occurs at the hinge. The umbo is moderately incurved. Cardinal extremities are square to bluntly rounded. Costae increase by bifurcation and have a density of 8–9 per 3 mm. at the anterior margin of the valve. Two large spine bases are present on the cardinal extremities and one spine base occurs on either side of the umbo ; approximately 6–8 smaller spine bases are present as a poorly defined concentric band well down on the trail.

Brachial valve is uniformly concave, being deepest towards the centre of the valve. Cardinal extremities are flat. Concentric lamellae are regular, overlapping, increase in length away from the umbo and are crossed by obsolete costellae. The lamellae are absent from the cardinal extremities and the valve is aspinose.

Internal. Pedicle valve. Adductor muscle scars with indistinct square outlines are situated high on the umbo and separated by a small elongate pit. Diductor muscle scars are obscure.

Brachial valve. Adductor muscle scars are smooth, round to ovoid, situated on high platforms and are separated by a thin median ridge which broadens anteriorly into a well defined median septum and extends for half the length of the valve (Text-fig. 5). Two elongate pits separate the median ridge and the adductor muscle platform. The cardinal process is broadly bifid internally and quadrifid externally. Pustules on the floor of the valve are arranged in an irregular radiate pattern and have a

TEXT-FIG. 5

The brachial interior of *Productina globosa* n. sp. showing the bilobate cardinal process, median septum, adductor muscle scars and weak lateral ridges. (Approx. ×4.)

density of 5–8 per sq. mm. Lateral ridges are divergent from the hinge-line and are weakly developed.

MEASUREMENTS (in mm.) :

	Length	Width at Mid-Line	Hinge Width
Pedicle valve			
Holotype	10	10	11
	8·5	8	9·5
	8 est.	8	9
Brachial valve			
Paratype F.5239	7	8 est.	7·5
	6·5	6	—
	6	9	8

REMARKS : The cardinal process of *P. globosa* resembles that of *P. fremingtonensis* (Reed) from the Lower Carboniferous Gattendorfia zone (1) of the Pilton Beds, Barnstaple, England, as described by Goldring (1955, p. 404–405, text-fig. 2, no. 5). Goldring's inclusion of this species in *Productina* Sutton has not been followed by Muir-Wood and Cooper who have placed it in *Productellina* Reed.

P. sampsoni (Weller) from the Lower Mississippian of U.S.A., figured by Muir-Wood and Cooper (1960, pl. 123, figs. 1–10), has a marked geniculation towards the front of the brachial interior. A fine radial ornament similar to that on the brachial valve of *P. globosa* is present on the brachial valves of *P. sampsoni* figured by Muir-Wood and Cooper. However, *P. sampsoni* as described by Weller (1914, p. 129–130, pl. 13, figs. 30–35) appears to have stronger costae on the brachial exterior.

P. parvulus (Winchell), described by Weller (1914, p. 128–129, pl. 14, figs. 24–25), has a similar shape to *P. globosa* but it is impossible to make a more detailed comparison because of the lack of internal details.

The specific name *globosa* is an indication of the shape of the pedicle valve.

OCCURRENCE : L.86 Lewinsbrook. Campbell (1958, unpublished Ph.D. thesis) has collected this species from Burindi Mudstones at Keepit Dam, on the Namoi River, approximately 500 feet above the Rangari Limestone and on a comparable horizon in Swain's Gully, Merlewood Section (Carey, 1937).

MATERIAL : F.5235–F.5248. *Holotype* F.5235, *paratypes* F.5236, F.5239.

Family ECHINOCONCHIDAE Stehli 1954
Subfamily ECHINOCONCHINAE Stehli 1954
Genus PUSTULA Thomas 1914 emend. Chao 1927 emend. Muir-Wood and Cooper 1960

TYPE SPECIES : *Producta pustulosa* Phillips, 1836.

DIAGNOSIS : See Muir-Wood and Cooper (1960, p. 250–251).

REMARKS : This material differs from the revised diagnosis of the genus in the following features :

(1) The ornament is both rugose and lamellose, but with the former predominating.
(2) The median septum varies from a thin ridge to a massive septum which is characteristic of the genus.
(3) The adductor muscle scars in the brachial valve are not strongly dendritic.

Its assignment to *Pustula* Thomas is based on the external spinose ornament and the structure of the cardinal process and the lateral ridges in the brachial valve.

From *Stegacanthia* Muir-Wood and Cooper the Lewinsbrook material differs in the features listed below.

(1) The spine bases are much shorter.
(2) The lamellose ornament, especially in the brachial valve, is subordinate to the rugose ornament.
(3) The structure of the cardinal process and lateral ridges is characteristic of *Pustula* rather than *Stegacanthia*.

Pustula multispinata n. sp.

Plate 4, figs. 9–14

DIAGNOSIS : Pedicle valve with obsolete sinus ; fold absent on brachial valve ; on median anterior portions of valves there are 15–18

spine bases per 5 mm. and 9–10 concentric lamellae or ribs per 10 mm.; variably developed median septum and possibly two pairs of small triangular adductor muscle scars present in the brachial valve.

DESCRIPTION: External. The shell is small for the genus and wider than long. Concentric lamellae and ribs bear regular rows of short spine bases having a density of 15–18 per 5 mm. on the median anterior portion of both valves. Spine bases are of a generally uniform size and have an average length of 0·3 mm. Spines are fragile, filamentous and extend up to 4 mm. from the anterior margin of the shell. Concentric ribs and lamellae have a density of 9–10 per 10 mm. on the median anterior portion of the shell and generally maintain that density towards the umbo. Brachial valves occasionally have a greater density, one specimen examined having approximately 20 lamellae and ribs per 10 mm. on the median anterior portion of the valve.

Pedicle valve is most strongly convex near the umbo. The umbo is slightly incurved over the hinge line and the greatest width occurs at the mid-line of the valve. The sinus is obsolete to absent. Postero-lateral extremities are flattened.

Brachial valve is shallowly concave with a small deep concave region at the umbo. A fold is absent.

Internal. Pedicle valve. The large flabellate muscle field is situated high on the umbo and extends anteriorly for one-fifth the length of the valve. Diductor muscle scars are poorly defined, squarish, longitudinally striated and are possibly in two pairs. Adductor muscle scars are placed on a narrow ridge separating the diductor muscle scars. The internal surface is marked by concentric bands and pustules.

Brachial valve. The muscle field is slightly elevated above the floor of the valve. Adductor muscle scars are divided by a faint antero-laterally directed ridge into median and lateral pairs. The median adductor muscle scars are elongate, narrow, teardrop-shaped and expand laterally. Lateral adductor muscle scars are small, triangular, slightly elevated and are placed towards the posterior portion of the median pair. Both pairs of adductor muscle scars are smooth. The median septum is variable in strength and extends half the length of the valve. Straight brachial ridges originate from the lateral margins of the muscle field and join a pair of flabellate brachial markings in the lateral portion of the valve. The cardinal process has a bifid internal surface and trilobate external surface. The two internal lobes are convex and divided anteriorly by a cone-shaped alveolus. The lobes curve posteriorly and the external trilobate face consists of the extension of the former two lobes plus a median lobe. The region between the outer and median lobes is deeply concave. Cardinal process is buttressed by two strong rounded ridges running parallel with the hinge-line.

MEASUREMENTS (in mm.):

Pedicle valve

	Length	Width
	25	27·5
Paratype F.5221	23·5	32
	21·5	25
	20	26
	19	27
	18	23

Brachial Valve

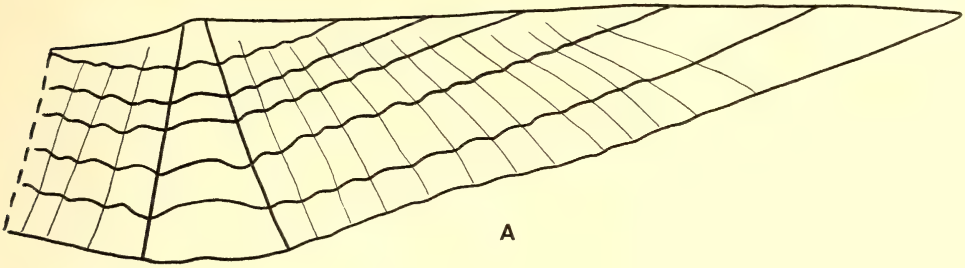
	Length	Width	Length Median Septum	Muscle Field Length	Muscle Field Width
Paratype F.5226	25	33	10 est.	—	8
	23·5	30	12 est.	—	—
	21·5	—	15	5	6
Holotype	18 est.	27	8	5	6
Paratype F.5219	18	25	—	—	—
	16·5	23	9	—	—
	15	22	—	—	—
	14	20	7	6	7

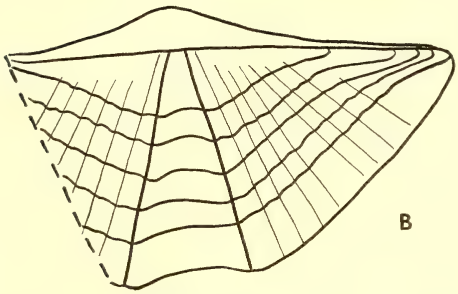
REMARKS: *Pustula multispinata* does not resemble any form previously described from the Carboniferous of Australia. *P. abbotti* Campbell (1956, p. 476–477, pl. 49, figs. 4–6) has a stronger sinus in the pedicle valve, a fold in the brachial valve, a larger median ridge and larger muscle scars in the brachial valve, a stronger cardinal process, 8–10 spine bases per 5 mm. and approximately 5 ribs per 10 mm., measured on the median anterior portion of each valve.

P. abbotti larga Cvancara (1958, p. 864–865, pl. 110, figs. 14–19) differs from *P. multispinata* in all the above features and has a considerably larger size.

P. gracilis Campbell (1956, p. 477–479, pl. 49, figs. 1–3) has 8 spine bases per 5 mm. and 7–9 concentric ribs per 10 mm. on the median anterior portion of the valves. The spines of *P. gracilis* are arranged in a quincuncial pattern.

On external features, the closest named overseas species is *P. subpustulosa* Thomas (1914, p. 278–281, pl. 20, figs. 1–2) from the Z_1 and Z_2 zones of England. The internal features of this form are unknown.





TEXT-FIG. 6
An illustration of the differences of the cardinal extremities of *Acuminothyris* (×3), A, and *Mucrospirifer* (×2), B.

P. chouteauensis Branson (1938, p. 40–41, pl. 3, figs. 23–24) from the Chouteau Limestone, Missouri, is distinguished from this species by its more transverse shape.

The external ornament of *P. praecedens* Stainbrook (1947, p. 312, pl. 46, figs. 24–26) from the Percha Shale, U.S.A., is coarser than that on *P. multispinata*.

The name *multispinata* refers to the numerous fine spines ornamenting the shell.

OCCURRENCE : This species is known only from L.86 Lewinsbrook.

MATERIAL : F.5218–F.5233. *Holotype* F.5218, *paratypes* F.5219, F.5221, F.5226.

Suborder SPIRIFEROIDEA Allen 1940
emend. Muir-Wood 1955
Superfamily SPIRIFERACEA Waagen 1883
Family SPIRIFERIDAE King 1846
Subfamily ACROSPIRIFERINAE Termier and Termier 1949
Genus ACUMINOTHYRIS n. gen.

TYPE SPECIES : *Acuminothyris triangularis* n. sp.

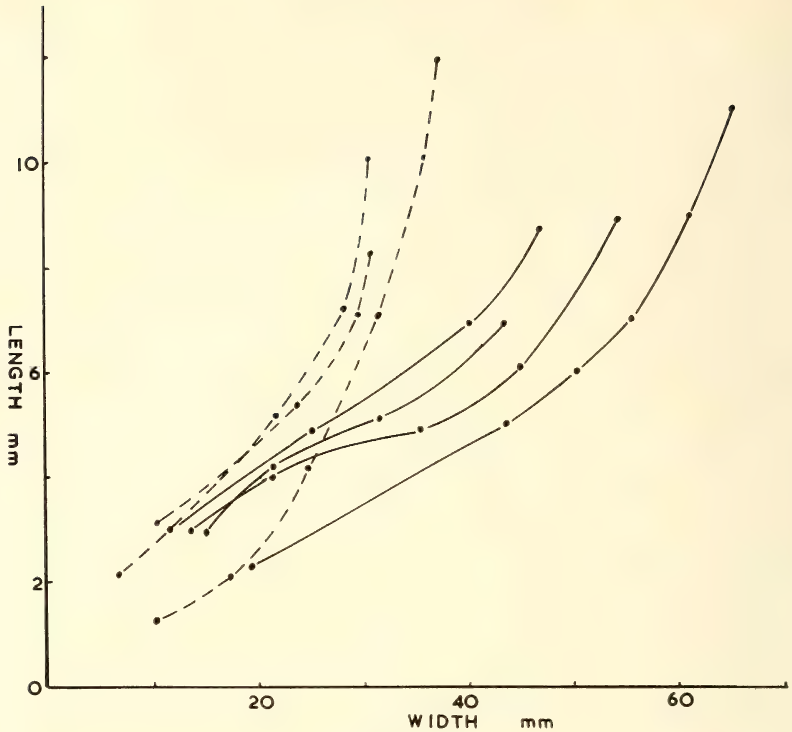
DIAGNOSIS : Unequally biconvex ; much wider than long ; cardinal extremities acutely angular ; hinge line denticulate ; ornament of plicae, regular sub-imbricating concentric lamellae and very faint radial lirae ; fold and sinus simple ; pedicle interior with short dental plates and faint myophragm ; brachial interior with short crural plates and low myophragm ; shell impunctate.

REMARKS : *Acuminothyris* differs from *Mucrospirifer* Grabau in having pointed rather than mucronate cardinal extremities in all but neanic growth stages (Text-fig. 6). In addition it has smaller sub-imbricating concentric lamellae when compared with the coarse lamellae ornamented with fine concentric growth lines in the latter genus. The different growth-trends in a species of each genus are shown in Text-figure 7.

The name *Acuminothyris* is derived from the Latin "*acumino*"—I sharpen.

Acuminothyris triangularis n. sp.
Plate 5, figs. 1–8

DIAGNOSIS : Shell narrowly triangular, 4–5 times as wide as long ; fold and sinus simple ; dental lamellae short ; shell thickened at the umbo ; crurae well developed ; 10–15 plicae on each lateral slope ; fine lamellose ornament with density of 12–14 per 3 mm. at the anterior margin.



TEXT-FIG. 7

Individual ontogenies of *Acuminothyris triangularis* n. sp. (solid lines) and *Mucrospirifer prolificus* (Silica Shales, Ohio) demonstrating the differences in growth of the two genera. Measurements on brachial valves.

DESCRIPTION: Exterior. The shell is slightly unequally biconvex, narrowly triangular, with acutely angular, flattened cardinal extremities. There are 10–15 low rounded plicae on each lateral slope. The lateral plicae become indistinct on the cardinal extremities. Regular sub-imbricating lamellae, with a density of 12–14 per 3 mm. at the anterior margin, are most prominent in the furrows between the plications and are crossed by a fine micro-ornament of radial lirae. At the cardinal extremities the lamellae become straight due to the obsolescence of the plicae. The shell is thickened at the umbo and around the shoulders lateral to the muscle scars.

Pedicle valve. Greatest convexity occurs at the umbo, where the beak is strongly incurved over the cardinal area. Cardinal area is low, concave and is 2 mm. high on a valve 44 mm. wide and 10·5 mm. long. It is ornamented with vertical striations and grooves and horizontal growth lines. The delthyrium is wide and open, except for a small triangular plate covering the apex. The delthyrial angle is 80°. Simple median sinus is sharply defined by high plicae and extends from the tip of the beak to the anterior margin of the valve. The sinal angle is 20°.

Brachial valve. The fold is well defined, rounded and expands slightly anteriorly. The cardinal area is low. Brachial valve is less convex than the pedicle valve.

Internal. Pedicle valve. The muscle field is divided down its entire length by a low distinct myophragm. Adductor muscle scars are poorly defined and occur on a ridge in the sinus of the valve. Diductor muscle scars are pointed posteriorly and broaden anteriorly, where they have smooth terminations. Those portions situated on the prominent plications bordering the sinus are strongly marked with longitudinal striations and are deeply impressed into the shell. Dental lamellae are short and are supported by a thickening on the umbonal shoulders. The teeth are well developed. Denticles along the hinge-line are more closely spaced towards the delthyrium and articulate with pits on the hinge of the brachial valve.

Pallial markings are variable ; vascula genitalia range from 8–9 irregular, non-branching, radiating blade-like trunks arising from the lateral margins of the diductor muscle scars (Text-fig. 8), to prominent genital pits associated with one, or possibly two, anteriorly directed vascula extensions following the grooves in the plications of the shell.

Brachial valve. Two pairs of adductor muscle scars occur between the large plications limiting the fold of the valve. The inner pair are long, narrow, pointed anteriorly, blunt posteriorly and occur in a shallow depression on either side of the myophragm. The lateral pair, between the inner pair and the large plications bordering the fold, are sharply pointed posteriorly and blunt anteriorly. A strong myophragm extends the length of the muscle field. Plicae bordering the muscle field are distorted, curve slightly outwards and are sharply defined. Cardinal process has up to 9 small vertical lamellar plates and is situated on a callus between the crural plates. Strong, slightly divergent crural plates are buttressed laterally by socket plates. Sockets are narrow, widely divergent and well defined.

MEASUREMENTS (in mm.) :

Pedicle Valve

	Length	Width	Muscle Field (at anterior end) Length	Width
	10	38	4·5	3
Holotype ..	8·5	42	4	3·5
	7·5	46	4·5	3
	6	28	4	2

Brachial Valve

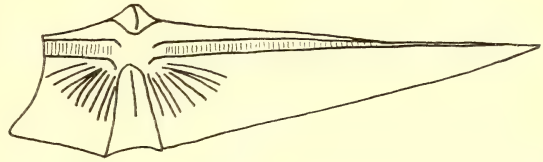
	Length	Width	Muscle Field (at anterior end) Length	Width
	13	74 est.	—	—
Paratype F.5172 ..	10	50 est.	—	—
Paratype F.5180*a* ..	10 est.	40	5	3
	9·5	40	4	3
	9	32 est.	—	—
	9	34	—	—
	8·5	38 est.	5	3·5
	8	39·5	—	—

REMARKS : The writer is not aware of any comparable species from Australia or overseas.

The specific name *triangularis* describes the general shape of the shell.

OCCURRENCE : This species occurs at L.215, L.217, L.86 Lewinsbrook, L.50 Gresford Quarry and L.233 Trevallyn.

MATERIAL : F.5170–F.5184. *Holotype* F.5170, *paratypes* F.5172, F.5180*a*.



TEXT-FIG. 8
Pedicle interior of *Acuminothyris triangularis* n. sp. showing vascula genitalia arising from around the muscle field (× 2·25).

Subfamily BRACHYTHYRINAE Fredricks 1924

Genus BRACHYTHYRIS McCoy 1884

TYPE SPECIES : *Spirifer ovalis* Phillips, 1836.

DIAGNOSIS : See Maxwell (1954, p. 26).

REMARKS : George (1927), in his definition of the genus *Brachythyris*, states that dental plates are absent. However, dental lamellae as defined by Browne (1953) are present, but the genus lacks adminiculae (Campbell, 1959).

Brachythris elliptica n. sp.

Plate 4, figs. 1–4

? Spirifer pinguis Sowerby, de Koninck, 1876, Pal. Fossils, N.S.W. Mem. Geol. Surv. N.S.W., Palaeontology No. 6, p. 185, pl. 14, figs. 2, 2*a*.

Spirifer pinguis Sowerby, Dun, 1902, Rec. Geol. Surv. N.S.W., 7, pt. 2, p. 84, pl. 22, figs. 1, 2, 5.

Non Spirifer pinguis Sowerby, Benson and Dun, 1920, Proc. Linn. Soc. N.S.W., 45, p. 348, pl. 21, figs. 9–11.

DIAGNOSIS : Wider than long ; hinge-line approximately two-thirds width of shell ; cardinal extremities well rounded, elliptical, flat and usually poorly plicate ; unequally biconvex ; pedicle valve much higher than the flat brachial valve ; commissure parasulcate.

DESCRIPTION : External. The shell is elliptical, unequally biconvex, with the pedicle valve having the greatest convexity. The hinge-line is straight and constitutes two-thirds the width of the shell. Up to 24 plicae broaden anteriorly, become lower laterally and are almost absent from the cardinal extremities. The plicae are separated by shallow sulci one-quarter the width of one plication and are crossed by weak concentric growth lines.

Pedicle valve. Greatest convexity occurs at the sharply pointed umbo. The umbonal tip is incurved over the cardinal area and may point anteriorly. The cardinal area is concave, two-thirds the width of the valve and is 7 mm. high on a shell 50 mm. long and 90 mm. wide. It is

ornamented with vertical striations having a density of 3–4 per mm. and horizontal growth lines. Delthyrium is open except for a small arched pseudodeltidial plate at its apex. The calcite of the plate is continuous with that of the shell. The delthyrial angle ranges between 75°–85°. Median sinus is narrow, well defined at the umbo and becomes broader and more shallow anteriorly. Its depth ranges from 1·5–3 mm. at the deepest part. The floor of the sinus is flat to slightly rounded and may bear an extremely faint plication ; up to three pairs of simple accessory plicae ornament the sides of the sinus. The sinal angle ranges from 15° to 25°.

Brachial valve is flat except for a slight umbonal convexity and the low median fold. The gently rounded fold broadens anteriorly and is more than twice as wide at the front than at the mid-point of the valve. The apex of the fold is ornamented by a well defined furrow arising at the umbo. Up to 3 smaller, more obsolete furrows are present on the sides of the fold, the outer furrow being the shortest. Three furrows are present only in gerontic specimens. A marked flexure at the mid-region of the valve coincides with an increased rate of (anterior) widening of the fold.

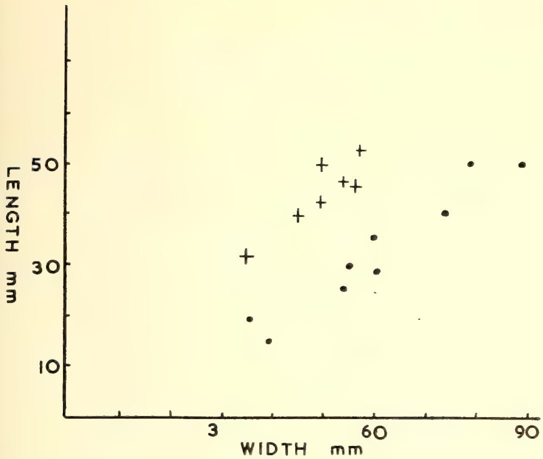
Internal. Pedicle valve. Long diductor muscle scars are bluntly pointed at the umbo, broaden anteriorly and end with laterally rounded terminations. They are deeply impressed at the umbo, become shallower anteriorly and are longitudinally or occasionally radially striate. Adductor muscle scars are long, narrow, pointed at both ends, situated in a well defined groove between the diductor muscle scars and are separated in their posterior portions by a short faint myophragm. They commence 3–6 mm. in front of the rear edge, and end 4–11 mm. in front of the termination of the diductor muscle scars. Large teeth are supported on well developed dental lamellae formed by a thickening on the inner edges of the delthyrium. The hinge-line is faintly denticulate. The shell is thickened around the umbo and towards the sides of the muscle field. Pallial markings are varied. Vascula genitalia are restricted to a region adjacent to the muscle field. In some specimens 11 or 12 simple trunks radiate from the muscle field through a pitted area (Text-fig. 11). In others there are no well defined trunks and a network of poorly defined ridges produces a striated appearance on either side of the muscle field.

Brachial valve. Adductor muscle scars are in two pairs. The inner pair, separated by a low narrow myophragm, is long, narrow, bluntly pointed towards the umbo, broadens anteriorly, terminates bluntly and is longitudinally striated. The outer pair is less well defined and occurs on the plicae bordering the fold of the valve. The myophragm arises a short distance from the blunt umbo, becomes less well defined anteriorly and terminates at the front of the muscle field. Strong socket plates enclose large striated sockets. Descending lamellae are attached to the inner edge of the

MEASUREMENTS (in mm.) :

Pedicle Valve	Length	Width	Height of Valve	Muscle Field: Length Diductor Scars	Muscle Field: Length Adductor Scars	Muscle Field: Width	Muscle Field: Depth
Paratype F.5185	50	—	10	13	20	13	4
Holotype ..	50	87 est.	—	12	—	12	—
	41	74	7·5	10	16	8	2
	38	60	7	9	15	7	2·5
	35	—	—	8	9	8	—
	30	56	5	8	12	7	1·5
	29	62	7	9	15	7	2·5
	25 est.	54	5	8	12	7	2
	20 est.	36	—	8	—	6	—
	15	39	2·5	5	7	4	—
	—	—	—	11	9	6	—

Brachial Valve	Length	Width	Height of Valve	Adductor Muscles: Length	Adductor Muscles: Width	Height of Fold
Holotype	50	87	—	—	—	2
	37 est.	70	—	—	—	—
	30	60	—	—	—	1
Paratype F.5191 ..	30	50	6	8	5	1·5
	28	52	5	7	6	1·5
	24	41	—	—	—	—
	9	18	—	—	—	—



TEXT-FIG. 9

Scatter diagram of length/width ratios of the pedicle valves of *Brachythris elliptica* n. sp. (circles) and *Brachythris pseudovalis* Campbell (plus signs)

socket plates. Cardinal process consists of approximately 20 small vertical plates placed on a callus between the socket plates.

REMARKS: A comparison of *Brachythyris elliptica* with *Spirifer pinguis* Sowerby, described by Davidson (1857, pl. 10, figs. 1–12), shows that the latter is not as wide, is more convex especially in the brachial valve and that the plicate ornament runs strongly to the lateral parts of the valves. Additional furrows are absent from the fold on the brachial valve.

The external ornament of *B. suborbicularis* Hall, described by Weller (1914, pl. 61, figs. 1–8), from the Burlington and Keokuk Limestones of Illinois, resembles that of *B. elliptica*. However, the former has smaller dental lamellae and a different length/width ratio.

B. willbourni Muir-Wood (1948, p. 45–47, pl. 8, figs. 1–3), from the Lower Carboniferous of Malaya, is more convex and has fewer plicae than *B. elliptica*, while the sinus on the pedicle valve is ornamented with 5–6 bifurcating or trifurcating plicae.

Campbell (1957) recognized that this species differed from *B. pseudovalis* Campbell (1957, p. 76–78, pl. 14, figs. 10–15) from Babbinboon, being consistently broader, more coarsely plicate and having a weaker umbo. Features of the latter species which differ from *B. elliptica* are: a cardinal area four-fifths the width of the shell ornamented with vertical striations having a density of 8 per mm.; the largely covered delthyrium with a delthyrial angle of 45°; and the presence of 14 plicae on each lateral slope.

Scatter plots (Text-fig. 9) show differences in the length/width ratios for *B. elliptica* and *B. pseudovalis*. Length/width plots of *B. elliptica* show irregularities during the early stages of growth of some specimens (Text-fig. 10).

OCCURRENCE: *B. elliptica* is known from L.215, L.216, L.217, L.86 Lewinsbrook, L.50 Gresford Quarry and L.208 Trevallyn.

MATERIAL: F.4803–F.4809, F.5185–F.5194.

Holotype F.5189, *paratypes* F.5185, F.5191.

Subfamily DELTHYRINAE Waagen 1883, Fredericks 1924

Genus DELTHYRIS Dalman 1828

TYPE SPECIES: *Delthyris elevata* Dalman, 1828.

DIAGNOSIS: Spiriferoid; greatest width at hinge-line; ornament of few simple plications and concentric lamellae; cardinal area relatively high; pedicle interior with well developed dental lamellae and median septum.

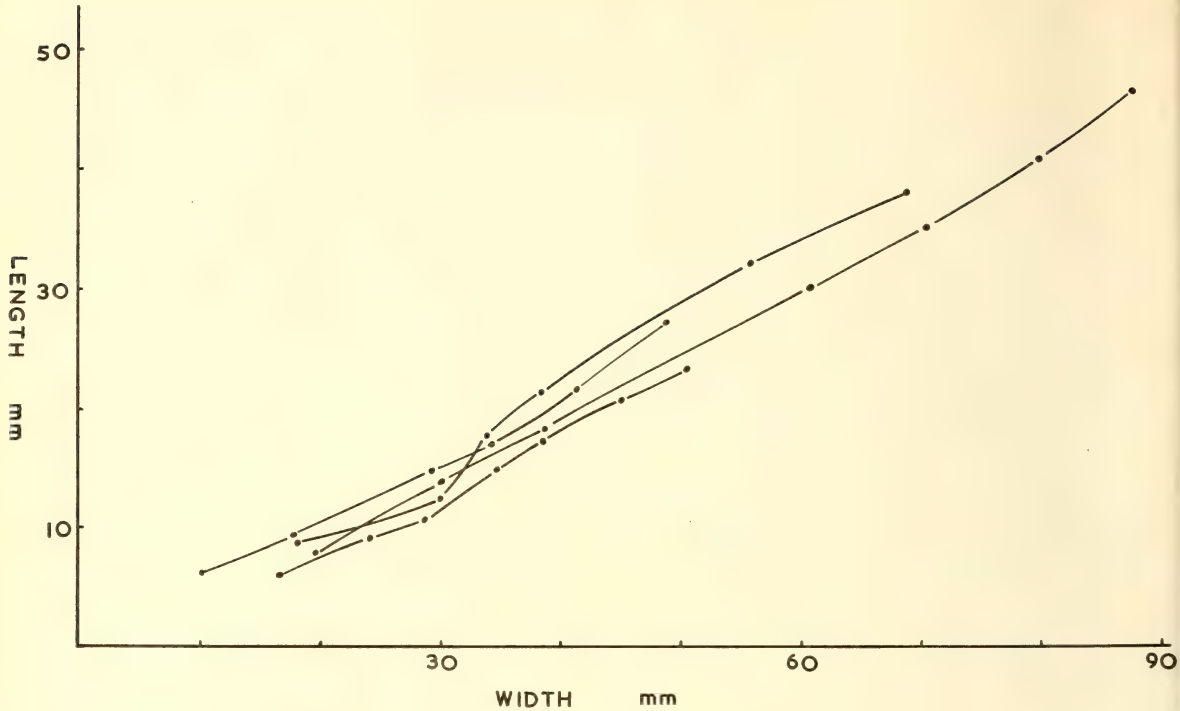
REMARKS: In this collection only one rather poorly preserved interior of the pedicle valve has been found. Despite the fact that no well developed septum and only poorly defined dental lamellae are present, this material has been provisionally placed in the genus *Delthyris* Dalman because of the simple plications, lamellose ornament and impunctate shell.

? Delthyris papilionis n. sp.

Plate 6, figs. 3–7

DIAGNOSIS: Almost plano-convex; three strong plicae on each lateral slope; imbricating concentric lamellae with density of 12–15 per 3 mm. on the mid-portion of the shell; cardinal extremities rounded; fold and sinus well developed; long adductor muscle scars in brachial valve; crural plates short; pedicle valve with poorly defined dental lamellae; median septum obsolete or absent.

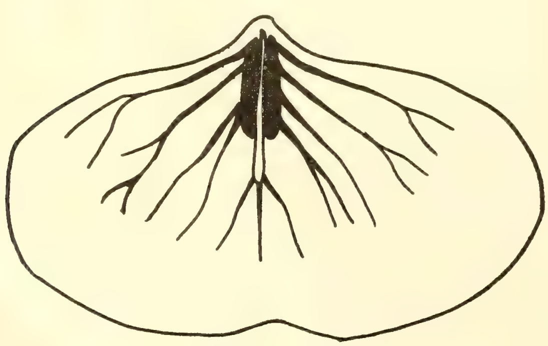
DESCRIPTION: External. The shell is unequally biconvex to plano-convex, semi-circular and wider than long, with the greatest width at the hinge-line. It is strongly plicate and has a simple fold and sinus. Three plicae on each lateral slope become lower laterally. The strongly imbricating concentric lamellae are crowded at the cardinal extremities, become longer anteriorly and have a density of 12–15 lamellae per 3 mm. on the mid-portion of the shell. Fine radial lirae have a density of 12–15 per mm. at the anterior margin. The shell material is impunctate.



TEXT-FIG. 10
Individual length/width ontogenies of four brachial valves of *Brachythyris elliptica* n. sp.

Pedicle valve is convex. Greatest height occurs at the bluntly pointed umbo which does not overhang the cardinal area. The prominent median sinus begins high on the umbo, broadens slightly anteriorly and is flanked by high plicae. The cardinal area is high.

Brachial valve is semi-circular and flat to shallowly convex, with the flattest area on either side of the umbo. Greatest convexity occurs at the anterior margin. The valve is slightly elevated at the umbo and compressed towards the rounded cardinal extremities. A weak rounded fold arises at the tip of the umbo and broadens anteriorly. The low cardinal area contains a broad triangular notothyrium.



TEXT-FIG. 11
Pedicle interior of *Brachythris elliptica* n. sp. showing branching vascula genitalia originating from the muscle field.

Internal. Pedicle valve. Diductor muscle scars are longitudally striate, elongate and are situated in the furrows of the plicae bordering the sinus. Adductor muscle scars are elevated on a sharp ridge in the sinus and are divided by a myophragm.

MEASUREMENTS (in mm.) :

		Length	Width
Pedicle Valve			
		6	10
Paratype F.5308	..	5	6
Brachial Valve			
		Length	Width
Holotype	.. ..	9·5	12
		8·5	11·5
		5·5	10
Paratype F.5312	..	5	9
		4	6

Brachial valve. Adductor muscle scars are elongate and extend from one-third to one-half the length of the valve. They are pointed towards the umbo, blunt anteriorly and occur

on the sides of the fold. Crural plates are short and blunt. Sockets are long, broadly rounded, strongly divergent from the hinge and are supported by strong narrow socket plates. Cardinal process consists of 7–8 small lamellar plates elevated on a callus between the crural plates. The internal surface bears impressions of the external concentric lamellae.

REMARKS : *? D. papilionis* resembles a number of the specimens referred to *D. novamexicana* Weller (1914, pl. 36, figs. 12, 13, 14, 20 and 21). These, however, differ in possessing mucronate cardinal extremities and a curved umbo on the pedicle valve.

The specific name is derived from the Latin "*papilio*", a butterfly, the shell resembling the shape of a butterfly.

OCCURRENCE : This species is known from L.86 Lewinsbrook and L.50 Gresford Quarry.

MATERIAL : F.5305–F.5313. *Holotype* F.5305, *paratypes* F.5307, F.5308, F.5312.

Subfamily AMBOCOELIINAE George 1931 emend. Vandercammen 1956

Genus THOMASARIA Stainbrook 1945 emend. Vandercammen 1956

TYPE SPECIES : *Thomasaria altumbona* Stainbrook 1945, p. 58–59, pl. 4, figs. 22–30.

DIAGNOSIS : See Stainbrook (1945, p. 57).

REMARKS : The genus *Thomasaria* was emended by Vandercammen (1956) to include two Belgian species. However, Vandercammen's emendation is not accepted because of positive differences between the Belgian material and the type species and because the type specimens were not examined when the changes to the concept of the genus were made.

The Belgian species described by Vandercammen, *Thomasaria gibbosa* Vandercammen and *T. parallela* Vandercammen, differ from the type species in the possession of a much lower cardinal area on the pedicle valve and in the presence of two narrow unfused deltidial plates extending along the entire length of the delthyrial margins. The deltidial plates on *T. altumbona* Stainbrook, the type species, are fused and extend half the length of the delthyrium, and the remainder of the delthyrial opening is covered by a separate plate.

These differences are sufficient to separate the Belgian material from *Thomasaria* sensu stricto. The species described below resembles the Belgian specimens and is referred to *? Thomasaria*. When sufficient material becomes available it should be referred to a new genus. The Belgian material, which appears to be congeneric with *? T. voiseyi*, occurs in rocks of Upper Givetian and Frasnian age.

? Thomasaria voiseyi n. sp.

Plate 4, figs. 5–11

DIAGNOSIS : Shell sub-ovate or pentagonal to sub-brachythyrid ; narrow sinus on pedicle valve ; poorly defined fold on brachial valve ; pedicle valve with prominent cardinal area ; ornament of up to 5 indistinct plicae in gerontic individuals, fine radial lirae, well developed concentric ornament and small paired spines ; sub-parallel dental lamellae extend for half the length of muscle field ; crural plates small, sub-parallel.

DESCRIPTION : External. The shell is small and varies in shape from sub-ovate and pentagonal in younger stages to sub-brachythyrid in gerontic individuals. The pedicle valve has the greater convexity. The shell is usually wider than long ; greatest width occurs near the mid-line, the hinge-line is approximately two-thirds the width of the shell and the cardinal extremities are well rounded. Ornament in gerontic individuals consists of up to 5 obsolete plications on each lateral slope. Younger specimens are smooth, or have one or two indistinct plications. Growth lamellae are prominent, widely spaced medially, but are crowded at the cardinal extremities. Short spines, approximately 0·2 mm. in length, may arise from the concentric lamellae and appear to have a paired arrangement. Very faint radial lirae are crowded at the umbo and extend to the margins of the shell, their density at the anterior margin being approximately 30 per 1 mm.

Pedicle valve is most convex in front of the umbo. The beak is moderately incurved. The median sinus has a rounded floor, contains no accessory ornament, is narrow at the umbo and becomes wider and less well defined anteriorly. The delthyrium is wide, triangular, open and has a delthyrial angle of approximately 80°. In a shell 17 mm. wide the delthyrium is 4 mm. wide and 2 mm. high. The cardinal area is sharply defined, moderately high and is ornamented with vertical striations and horizontal growth lines.

Brachial valve has a slight even convexity. The fold is extremely obsolete, broadly rounded and does not extent on to the umbo. The cardinal area is small, with a very shallow notothyrium.

Internal. Pedicle valve. Diductor muscle scars are long, narrow and broaden slightly anteriorly. They are pointed towards the umbo, blunt anteriorly, longitudinally striate and are well impressed into the shell. Adductor muscle scars are long, narrow, often poorly defined and are situated on the median ridge. In some cases they extend past the anterior termination of the diductor muscle scars. Dental lamellae are narrow, sub-parallel and extend anteriorly for about one-half the length of the muscle field. From beneath the teeth they become rapidly lower anteriorly. Teeth are blunt, divergent and strongly developed. Pallial markings are restricted to a small area lateral to the muscle field. Vascula genitalia range from faint trunks arising near the diductor muscle scars to radiating striations associated with numerous pit-like depressions.

Brachial valve. Adductor muscle scars are narrow, bluntly rounded posteriorly, widen anteriorly and end in a square termination. They are situated high on the umbo and are slightly impressed and longitudinally striated. An outer pair of adductor muscle scars is very poorly defined. The extremely obsolete myophragm is best developed in the median and anterior portions of the muscle field. Socket plates are supported by small slightly divergent to sub-parallel crural plates. In a valve 16 mm. wide and 13 mm. long the crural plates are 1 mm. long. The cardinal process is triangular, having 5–7 vertical lamellar plates. Faint radial vascula genitalia arise from the muscle field.

MEASUREMENTS (in mm.) :

Pedicle Valve

	Length	Width	Muscle Field Length	Muscle Field Width
	16	19	5	2
Holotype	14	17	7	3
	13	17	7	2·5
	12	14	4	2
	12	12·5	5	2·5
	11·5	14	4	2
	11	16	5·5	2
	10·5	12	—	—
	10	16	5	2
	10 est.	16	5·5	2
	8	8	3	1·5 est.

Brachial Valve

	Length	Width	Muscle Field Length	Muscle Field Width	Width of Hinge
Paratype F.5202	13	15·5	5	2	8
Paratype F.5214	12	18	—	—	10
	10	16	—	—	7
	9	11	3·5	2	5

REMARKS : *? Thomasaria voiseyi* differs from *T. altumbonata* Stainbrook (1945, p. 58–59, pl. 4, figs. 22–30) from the Independence Shale, Iowa, the latter having a very high cardinal area and a stronger fold in the brachial valve.

Strongest resemblance is to *? T. parallella* Vandercammen (1956, p. 26–29, pl. 11, figs. 1–6). *? T. voiseyi* is larger, has a more pentagonal brachial valve, stronger concentric ornament and a very fine radial ornament. *? T. parallella* occurs in the Frasnian of Belgium.

This species is named after Professor A. H. Voisey, Department of Geology, University of New England.

OCCURRENCE : *? T. voiseyi* is known only from L.215 and L.86 Lewinsbrook.

MATERIAL : F.5195–F.5217. *Holotype* F.5195, *paratypes* F.5205, F.5214, F.5216.

Superfamily ROSTROSPIRACEA Schuchert and Le Vene 1929
Family ATHYRIDAE Davidson 1884
Subfamily ATHYRINAE Waagen 1883
Genus CLEIOTHYRIDINA Buckman 1906

TYPE SPECIES : *Spirifer deroyssii ;* L'Eveillé, 1835.

DIAGNOSIS : See Maxwell (1954, p. 42).

Cleiothyridina segmentata n. sp.
Plate 6, figs. 10–12

DIAGNOSIS : Sub-equally biconvex ; lamellar fringe one-third to one-quarter length of valve joining spines around margin of shell in older specimens ; long thin spines in young shells ; strong concentric lamellae ; fold and sinus obsolete or absent ; teeth long and rounded ; narrow pedicle cavity.

DESCRIPTION : External. The shell is small to medium sized for genus. It is sub-equally biconvex, ovate to sub-quadrate in shape and has an approximately equal length and width. Greatest width occurs at the mid-line. The hinge-line is short. Concentric lamellae are broad, irregularly spaced, strongly overlapping and have a spinose fringe. The lamellae are usually closely spaced on juveniles, but become widely spaced in older individuals where growth lines occur between the lamellae. Spines in young shells are thin and sharp, but become thick, flattened and bluntly pointed in gerontic forms. In these forms a thin lamellar extension of the shell joins the spines around the lateral and anterior margins, forming a fringe often one-third to one-quarter the length of the shell.

Pedicle valve is more convex than the brachial valve. The umbo is slightly incurved over the

opposite valve and has a round pedicle foramen at its tip. The sinus is variably developed and is usually absent in young individuals. When present, it commences on the umbo and becomes obsolete anteriorly.

Brachial valve is uniformly convex. The fold is obsolete and may form a slightly raised area in the mid-part of the valve.

Internal. Pedicle valve. The muscle field is very poorly defined. Dental lamellae bordering the pedicle cavity are short and divergent. Teeth are long, rounded and wider than the dental lamellae. The pedicle cavity is narrow and incurved at the umbo.

Brachial valve. Adductor muscle scars extend from near the umbo to the mid-point of the valve. They are pointed posteriorly, become slightly wider anteriorly, end in a pointed termination and are separated by a myophragm in their posterior portions. Two straight vascula media branch from near the posterior tip of the muscle field and extend to the antero-lateral margins of the valve. The hinge-plate is flanked by two broad widely divergent crural plates which form the inner boundary of the sockets.

MEASUREMENTS (in mm.) :

Pedicle Valve

	Length	Width	(With Spine (Fringe) Length	Width
	23	26	—	—
Paratype F.5323	18	22	24	32
	18	20	26	—
Paratype F.5322	16	18	23	30
	13	14	—	—
	10	9	—	—

Brachial Valve

	Length	Width
Holotype ..	13	13
Paratype F.5325	14	15
	9	10

REMARKS : *Cleiothyridina glenparkensis* Weller (1914, p. 473–474, pl. 78, figs. 21–24), from the Kinderhook Group, Mississippi Valley, resembles *C. segmentata* in external features, but has a more convex brachial valve. Its internal details are unknown.

The name for this species is the Latin for trimmed or ornamented ; the lamellar fringe trims the shell.

OCCURRENCE : This species occurs at L.86 Lewinsbrook.

MATERIAL : F.5320–F.5328. *Holotype* F.5320, *paratypes* F.5321–3, F.5325.

Cleiothyridina squamosa n. sp.

Plate 6, figs. 8–9

DIAGNOSIS : Small, ovate to elliptical ; sub-equally biconvex ; imbricating lamellae with scaly spines having a density of 12 per 3 mm. at anterior margin ; pedicle valve with large pedicle cavity, short curving dental plates and long teeth ; brachial valve with long median septum commencing in front of the muscle field ; large sockets parallel with hinge-line.

DESCRIPTION : External. The shell is small, ovate to transversely elliptical and sub-equally biconvex. It is slightly wider than long, the greatest width occurring at the mid-line. Cardinal extremities are well rounded and the hinge-line is short and straight. Anterior margins of the concentric lamellae are produced into a serrated band of imbricating spines which overlap in a regular manner and produce an indistinct radial ornament. The density of spines at the anterior margin is 12 per 3 mm.

Pedicle valve is moderately convex. Cardinal extremities are almost flat. The beak is straight, bluntly pointed and has a round pedicle foramen at its tip. Cardinal area is inconspicuous. The sinus is shallow and rounded on the umbo, but becomes obsolete before reaching the mid-portion of the valve.

Brachial valve is slightly more convex than the pedicle valve. The beak is incurved beneath the opposite valve.

Internal. Pedicle valve. The muscle field occurs in front of the pedicle cavity. Adductor muscle scars are bluntly rounded posteriorly, pointed anteriorly, occur on either side of a myophragm and are well impressed posteriorly. Curving diductor muscle scars are elongate and narrow towards the umbo, broadly rounded and extend in front of the adductor muscle field. Vascula media run from the front of the adductor muscle scars to the anterior margin of the valve. The diductor muscle field subtends 2 pairs of vascula genitalia. The outer vascula genitalia originate on the lateral margins of the muscle scars and extend to the antero-lateral margins of the valve. The inner vascula genitalia extend from the front of the muscle field to the anterior margin of the valve. The myophragm separating the adductor muscle scars becomes broader, higher and more rounded anteriorly. The large pedicle cavity is bordered by short curving dental plates. Teeth are long, wide, incurved and parallel with the hinge-line.

Brachial valve. Adductor muscle scars are elongate, elliptical and terminate near the mid-point of the valve. They are slightly

impressed towards the umbo and are separated posteriorly by a strong median septum extending one-quarter to one-sixth the length of the valve. The triangular hinge-plate has a foramen at its apex. Crural plates are weak and do not extend to the floor of the valve. Sockets between the crural plates and margins of valve are elongate and parallel with the hinge-line. The interior of the valve bears faint impressions of the external ornament.

Measurements (in mm.):

	Length	Width
Pedicle Valve		
Holotype ..	10	12·5
Brachial Valve		
Holotype ..	10·5	12·5
Paratype F.5330	10	12·5
Paratype F.5331	8·5	10

Remarks: *C. squamosa* does not resemble any previously described species from the Carboniferous of Australia. It is distinguished from *C. transversa* Maxwell (1954, p. 46, pl. 6, figs. 5–6) from Mt. Morgan, Queensland, by its approximately equal length and width.

The specific name is taken from the Latin "*squamosus*", scaly, referring to the ornament of flat overlapping spines.

Occurrence: This species is known only from L.215 and L.86 Lewinsbrook.

Material: F.5329–F.5331. *Holotype* F.5329, *paratypes* F.5330, F.5331.

Suborder RHYNCHONELLOIDEA Moore 1952
Superfamily RHYNCHONELLACEA Schuchert 1896
Family CAMAROTOECHIIDAE Schuchert and Le Vene 1929
Subfamily CAMAROTOECHIINAE Schuchert and Le Vene 1929
Genus Camarotoechia Hall and Clarke 1893

Type species: *Atrypa congregata* Conrad, 1841.

Diagnosis: See Sartenaer (1961, p. 5–7).

Remarks: As a result of the work of Sartenaer (1961) the concept of *Camarotoechia* has been restricted and the genus is now confined to a small number of Devonian forms. It should not strictly be applied to the species described below but until the Carboniferous rhynchonelloid genera have been revised this material is best referred to "*Camarotoechia*".

"*Camarotoechia*" sp. A
Plate 4, figs. 12–14

Description: External. Shell is rhynchonelliform, small, sub-triangular to sub-ovate and approximately as wide as long. The greatest width occurs at the mid-line. Lateral margins meet the beak at an angle of 75° and the anterior margin is gently convex or straight. Both the fold and sinus are weak and plicate. Plicae are strong, rounded and ornamented by weak concentric growth lines.

Pedicle valve is low, with a slight uniform convexity disrupted anteriorly by the median sinus. The beak is small and straight. The sinus originates at the mid-length of the valve, extends to the anterior margin, contains 3 small plicae and is bordered by two large plicae.

Brachial valve has an even convex curvature. A faint fold commences at the mid-line of the valve. There are three to four small plicae on each lateral slope.

Internal. Pedicle valve. Muscle scars have not been observed. Dental lamellae are small narrow, sub-parallel to slightly divergent and extend for one-eighth the length of the valve.

Brachial valve. Muscle scars have not been observed. The median septum is strong, sharp, extends one-third the length of the valve and divides posteriorly, forming a very small crural trough. The weak sockets are placed at an angle to the hinge. The hinge-plate is obscure.

Measurements (in mm.):

	Length	Width
Pedicle Valve		
	9	9
	8	8
	8	8·5
Brachial Valve		
	6·5	8

Occurrence: This species occurs at L.86 Lewinsbrook.

Material: F.5314–F.5319.

Pelecypoda

Family AVICULOPECTINIDAE Etheridge Jr. emend. Newell 1937
Subfamily STREBLOCHONDRIINAE Newell 1937
Genus Streblochondria Newell 1937

Type species: *Aviculopecten sculptilis* Miller.

Diagnosis: See Newell (1937, p. 80).

Remarks: This material differs from the type species of the genus in having almost sub-equal auricles. The type species, described by Newell (1937), is characterized by a larger anterior auricle.

Streblochondria obsoleta n. sp.
Plate 6, figs. 1–2

Diagnosis: Slightly opisthocline; auricles sub-equal; anterior auricle on right valve flat to concave and strongly ornamented; anterior auricle on left valve convex, smooth; very deep anterior auricular sulcus; costate ornament only on dorsal anterior margin of shell.

Description: The shell is orbicular, approximately as high as long, very slightly opisthocline and moderately convex, with the right valve having approximately the same convexity as the left. The hinge-line is straight. Auricles are small and sub-equal. The anterior auricle is moderately short with a smoothly rounded lateral termination. It is convex on the left valve and flat to gently concave on the right valve. The posterior auricle is not sharply separated from the body of either valve and has a gently rounded posterior margin continuous with that of the shell. The anterior auricular sulcus is narrow and deeply impressed. Byssal sinus occurs as a long narrow rectangular groove extending almost the entire length of the anterior auricle. The umbonal angle is approximately 75°. The anterior umbonal margin is slightly curved and the posterior margin straight. The resilifer has not been observed.

Ornament on the body of the shell consists of an extremely fine lattice formed by the intersection of fine radial costae with overlapping concentric filae; 12–14 costae present on the dorsal anterior portion of the shell become obsolete towards the ventral margin and are generally absent from the umbonal regions of the shell. Costae are weaker on the left valve. Concentric ornament is pronounced on the body of the shell and passes smoothly on to the posterior auricle. The anterior auricle on the right valve is strongly ornamented with 3–4 well developed costae crossed by very coarse imbricating lamellae. On the left valve the anterior auricle is smooth. The interior of the shell is smooth except for large growth lines bearing traces of concentric ornament.

Measurements (in mm.):

		Length	Height
Holotype F.5752*a*	..	16	15
Paratype F.5752*b*	..	13	12·5

Remarks: The form referred to *Aviculopecten ptychotis* McCoy by Etheridge and Dun (1906, pl. 15, figs. 5, 6, 7), from near Gresford, N.S.W., has a larger anterior auricle than this species. Etheridge and Dun's description is apparently based upon the specimen in fig. 5; figs. 6 and 7 have smaller sub-equal auricles and probably belong to a different species.

The larger anterior auricles and coarser ornament over the body of the shell distinguishes the species of *Streblochondria* described by Newell (1937) from *S. obsoleta.*

S. anisotum (Phillips), described by Hind (1903, p. 104–105, pl. 21, figs. 13–20), resembles *S. obsoleta* but is distinguished by a larger anterior auricle.

The specific name is from the Latin "*obsoletus*", indistinct, and refers to the indistinct ornament on the greater portion of the shell.

Occurrence: This species is so far known only from L.86 Lewinsbrook.

Material: F.5752–F.5754. *Holotype* F.5752*a*, *paratypes* F.5752*b*, F.5753, F.5754.

Arthropoda

Sub-Phylum TRILOBITOMORPHA Størmer 1944
Class TRILOBITA Walch 1771
Superfamily PROETACEA Salter 1864
Family PHILLIPSIIDAE Oehlert 1886

Remarks: The form of the glabella and cephalon of this material is similar to that found in the family *Proetidae* Salter 1864, but the distinctive pygidium leaves no doubt of its reference to the family *Phillipsiidae.* This resemblance has been previously noted by Weber (1937).

Genus Conophillipsia n. gen.

Type species: *Conophillipsia brevicaudata* n. sp.

Diagnosis: Glabella short, tapering anteriorly, usually separated from upturned striate border by a narrow furrow; basal lobes broad and convex; glabella furrow 2p clearly defined, 3p may be absent; fixed cheeks narrow; facial sutures divergent anteriorly, curve almost to glabella at posterior margin of eyes, cut posterior border at an acute angle; lunate, convex eyes faceted. Free cheeks convex, with elevated striate margin; more coarsely granular than glabella; genal spines present. Number of thoracic segments unknown. Pygidium with 13 axial rings and 11 ribs; axis convex, terminating well in front of posterior border; ribs run to margin anteriorly, become shorter posteriorly.

Remarks: The affinities of this genus with the *Proetidae* and the *Phillipsiidae* have been noted in the remarks on the family.

From *Phillipsia* Portlock this genus differs in the possession of a short tapering glabella and in the number of axial rings and ribs on the pygidium.

Proetus Steininger has a similar cephalon but an entirely different pygidium.

Other species which belong to *Conophillipsia* are *Phillipsia woodwardi* Etheridge and the closely related Russian species, *P. labrosa* Weber and *P. kazakensis* Weber. The Russian forms occur in the Lower Tournaisian Kassin Beds (Weber, 1937) and the Transition Beds (Nalivkin, 1937) of Kazakhstan. The precise stratigraphic occurrence of *P. woodwardi* Etheridge is unknown.

The type material from Lewinsbrook is fragmentary, but since elements of the cephalon, portions of the thorax and pygidia have been found within a few millimetres of one another there can be little doubt that they belong to the one species and possibly to the one specimen.

The generic name refers to the shape of the glabella which is cone-like in section.

Conophillipsia brevicaudata n. sp.

Plate 6, figs. 13–20

Diagnosis: Glabella sub-parallel, gently tapering, smooth; deep preoccipital furrows; 2p furrow short, 3p absent; facial sutures with laterally curving pre-ocular branch; post-ocular branch runs parallel with the glabella for a short distance past the eye and then swings abruptly outwards; free cheeks longer than broad and marked with very fine granular ornament; borders ornamented by concentric ridges. Pygidium with abruptly terminating axis; 13 axial rings and 11 distinct ribs in pleural region; smooth area between posterior ribs and posterior axial segment.

Description: Cranidium. The cephalon is approximately twice as wide as long, convex laterally and longitudinally and semi-elliptical in shape.

Viewed from the side the gently convex glabella has a broadly rounded mid-region, a deep occipital furrow and a strongly convex occipital ring. The anterior border and the small pre-glabellar field are abruptly upturned.

In plan view the glabella tapers slightly anteriorly and has an evenly rounded termination. Two preoccipital lobes are convex, triangular and defined by the strong 1p furrow. The 2p furrow is faintly to moderately developed and runs slightly postero-laterally. The occipital ring is convex and wider than the glabella. Palpebral lobes are well developed near the eyes and extend posteriorly as very narrow flanges between the glabella and the facial sutures. Facial sutures are close to the axial furrows immediately in front of and behind the eyes; pre-ocular portions curve smoothly outwards, leaving a wide area of fixed cheek lateral to the front of the glabella; post-ocular portions at first continue in a straight line posteriorly, but then swing abruptly outwards, crossing the posterior border approximately mid-way between the glabella and the lateral border at an acute angle. The anterior border furrow is deep and well defined. The fixed cheek is flat to slightly convex, extremely narrow in its posterior region and becomes wider at the front of the glabella. Free cheeks are longer than broad. The lateral borders are strongly defined by a deep lateral furrow, are raised above the outer edge of the free cheek and end posteriorly in short genal spines. The border is ornamented with fine concentric ridges. Towards the eyes the free cheeks are convexly rounded and stand above the more depressed areas marginal to the border furrows. Posterior border is less well defined, upturned and also striate. Eyes are large, crescentic, strongly arched and are situated high above the level of the free cheek. They are half as long as the glabella (without the occipital ring). The eyes are holochroal, their surface being covered by minute regular hexagonal facets having an approximate density of 4–5 per $0 \cdot 1$ sq. mm. A deep furrow separates the base of the eye from the elevated portion of the free cheek. The glabella is smooth and devoid of ornament, the free cheeks are marked by a fine granular ornament, while the lateral and anterior borders and the outer parts of the posterior border are ornamented by 3–4 terrace lines. The doublure has similar terrace lines. No details of the rostrum or hypostome have been observed.

Thorax. The number of segments in the thorax is unknown. The axis is moderately convex and slightly higher than the pleurae. Axial rings are not inflated laterally. The axial furrow is widest in the mid-portion of the axis and becomes more narrow towards the margins. Pleurae are flat towards the axis and are bent downwards in their outer portions. Pleural furrows are deep.

Pygidium. Pygidium is semi-elliptical, broader than long, with a prominent abruptly terminating axis.

In plan view the axis, which is strongly outlined by deep axial furrows, tapers posteriorly

and ends abruptly in a high square termination well forward of the posterior margin. The anterior end of the axis is approximately the same width as each pleuron. The axis contains 13 distinct axial rings which are inclined forwards and are separated by deep ring furrows. The rings become narrower posteriorly. Convexity of the axial rings decreases towards the axial furrows, resulting in the formation of a flat area along the axial margins. Eleven distinct ribs occur on each pleural region. The ribs are broad, separated by well rounded furrows, gently inclined anteriorly and become slightly broader and lower laterally. The posterior portions of the ribs are high, rounded and much more strongly developed than the anterior portions. All except the first rib curve gently backwards; rib 1 is normal to the axis for the initial one-third to one-half of its length and then curves abruptly backwards; ribs 1–3 run to the margin, while the remainder become progressively shorter, leaving a smooth border on the posterior of the pygidium. Pleural furrows are obsolete. Both the ribs and axial ring are marked with a very fine granular ornament.

Viewed from the side, at the front of the pygidium, the axis is one and a half to twice as high as the pleural lobes. It becomes gradually lower towards the terminal axial piece where the axis is abruptly truncated. The pleural region is moderately convex and also slopes gradually posteriorly. The convexity of the pleural field obscures all except the most posterior portion of the axial furrow. The smooth border is slightly upturned and posteriorly is separated from the pygidium by a broad obsolete furrow. The doublure is at least twice as wide as the border and is marked by 6–7 terrace lines.

MEASUREMENTS (in mm.):

Cranidium

	Length	Length of Glabella	Width of Glabella
Paratype F.5769*c*	7·5	6	—
	6	4·5	3·5
Holotype ..	6·5 est.	5	4
	5	4	3
	5	3·5	3

Pygidium

	Length	Width (Anterior)	Axis: Length	Axis: Width (Anterior)
Paratype F.5769*a*	9	10	7	3·5
	8	10	7·5	4
Paratype F.5776	6	8·5	5·5	3

REMARKS: The majority of Mitchell's specimens (Mitchell, 1918) of *Phillipsia woodwardi* Etheridge have been examined by the author. That species, now referred to *Conophillipsia*, is much larger than *C. brevicaudata*, has a relatively shorter and more convex glabella with a 3p glabella furrow and a more convex pygidium in which the axis is less abruptly truncated and the posterior border is weaker.

P. woodwardi is known from Crows Nest, Stony Creek at Stanwell and from Trilobite Ridge at Mt. Morgan, Queensland.

C. labrosa (Weber), described as a *Phillipsia* species by Weber (1937, p. 34–35, pl. 3, figs. 32–34), is usually larger, although figure 32*b* is approximately the same size as the present species. The former is characterized by a more convex glabella, which usually abuts against the upturned brim, and the presence of a 3p lateral glabella furrow.

C. kazakensis var. *paucicostata* (Weber), also described as a *Phillipsia* species by Weber (1937, p. 36, pl. 4, figs. 6, 8–11), is slightly smaller than this species, but has a more rounded axial termination, 13–14 axial rings and 9–10 ribs on the pygidium.

The specific name *brevicaudata* refers to the abrupt ending of the axis on the pygidium.

OCCURRENCE: This species is known only from L.86 Lewinsbrook.

MATERIAL: F.5766–F.5782. *Holotype* F.5766, *paratypes* F.5767–5770, F.5776.

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(Received 14 September, 1961, as revised 15 November, 1963)

Explanation of Plates

PLATE 1

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PLATE 2

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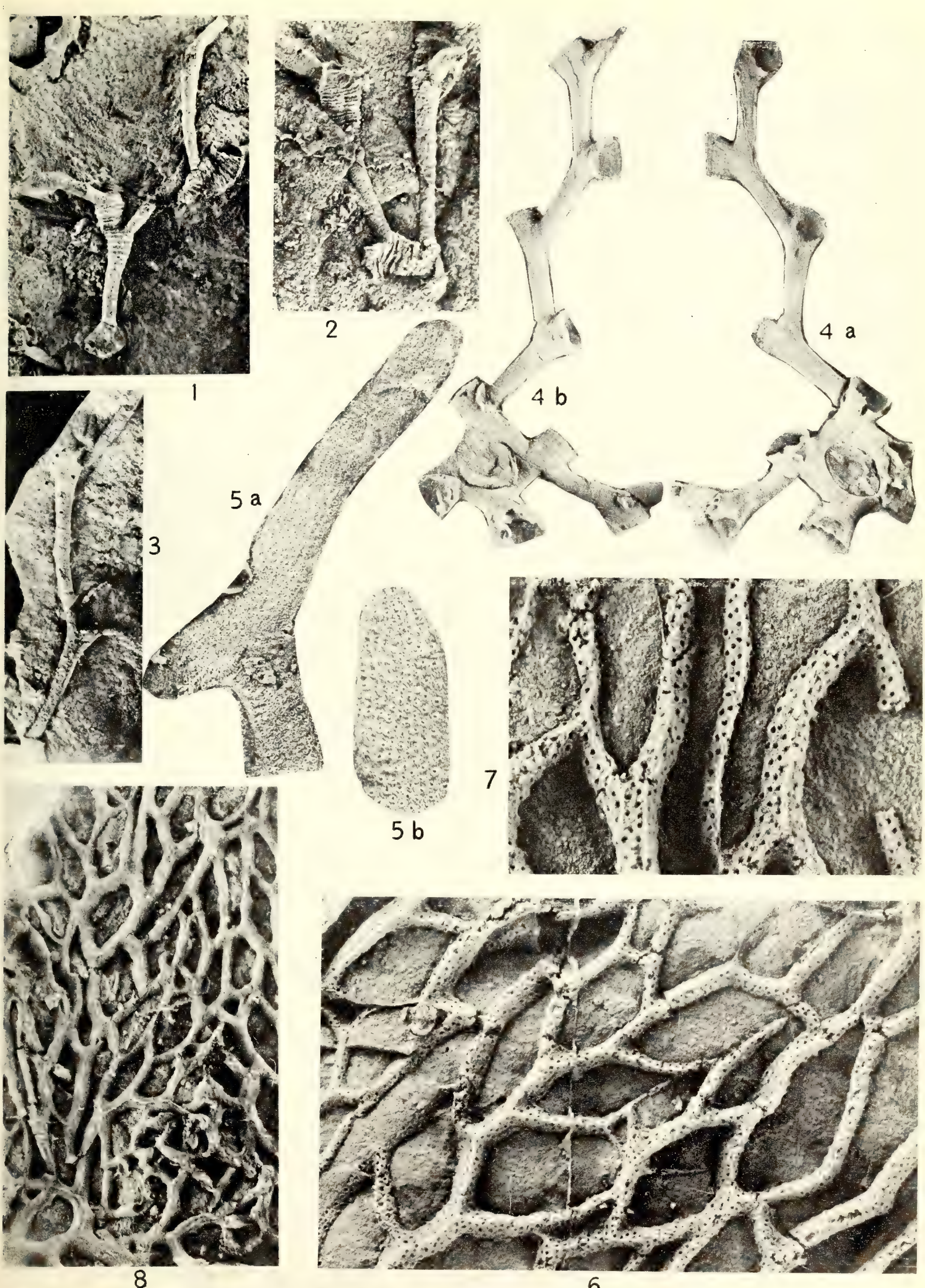
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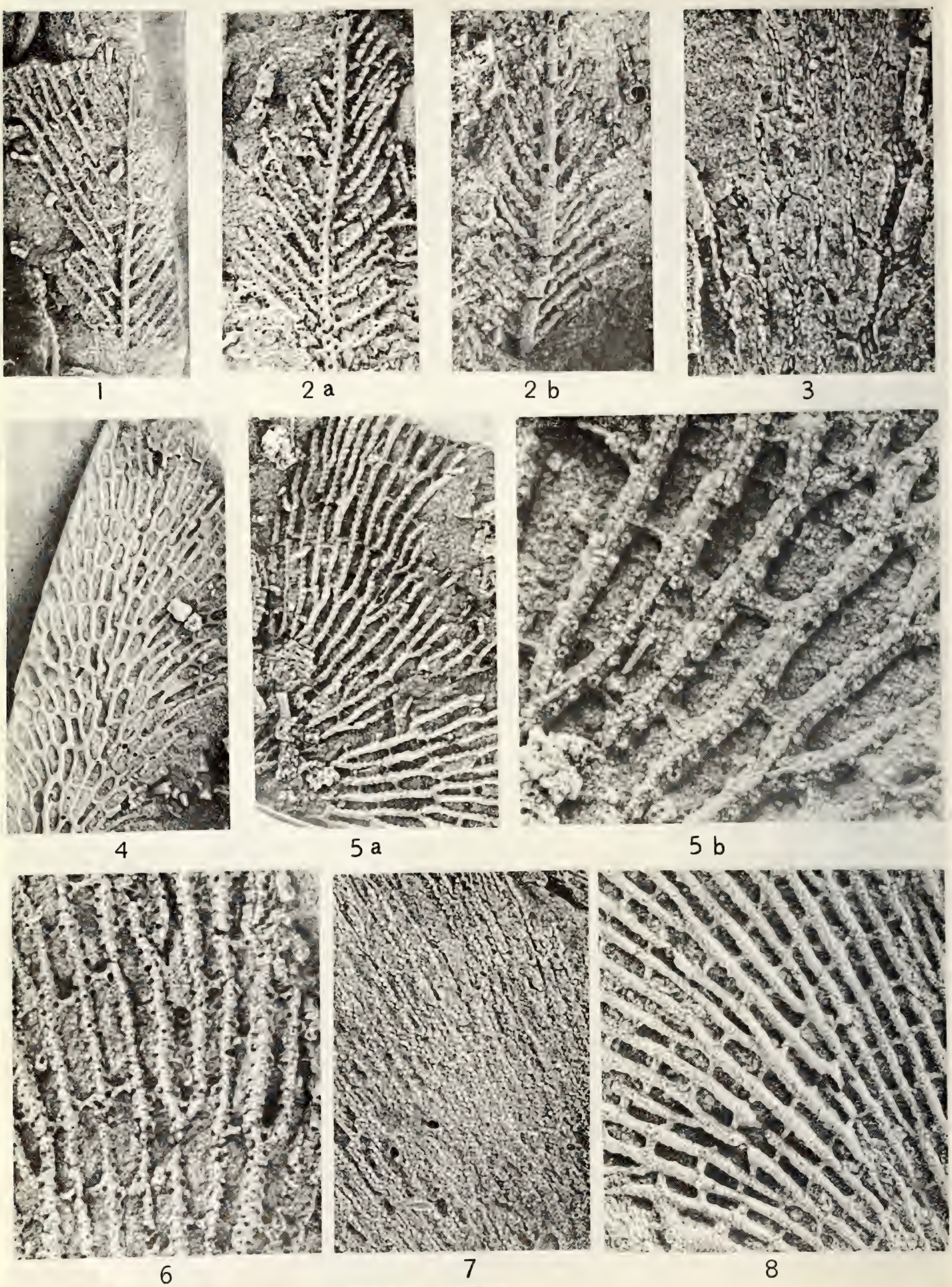
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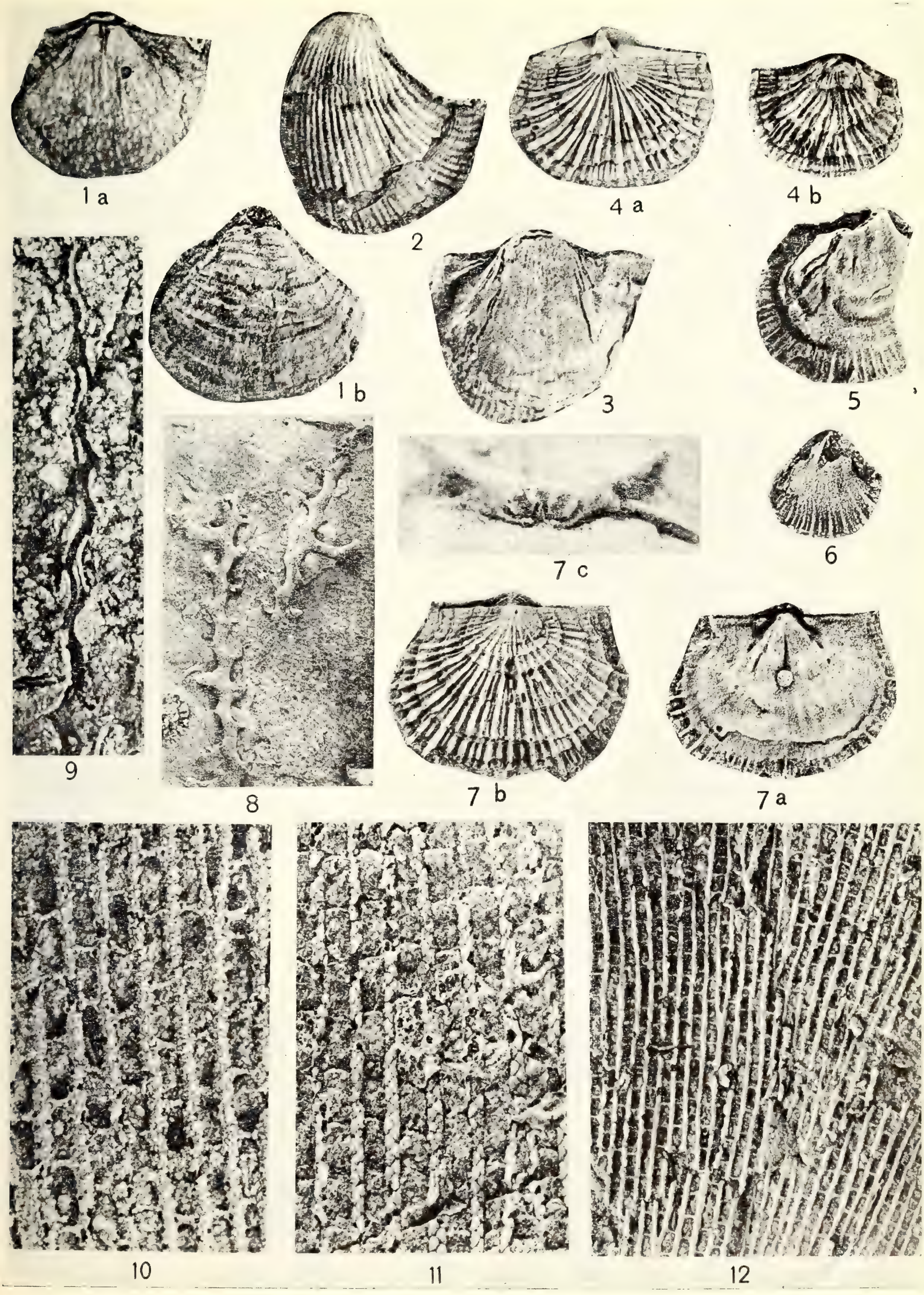
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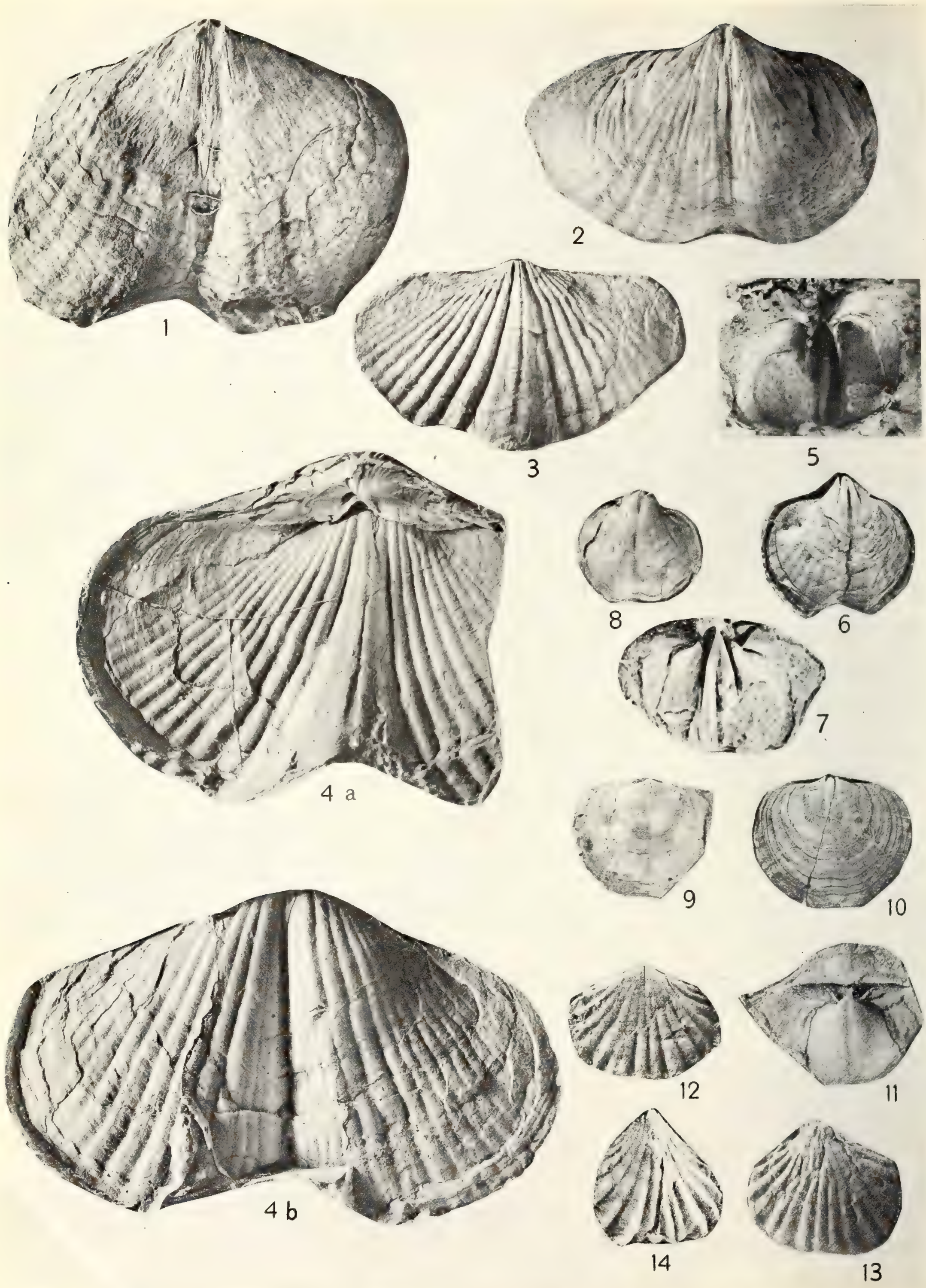
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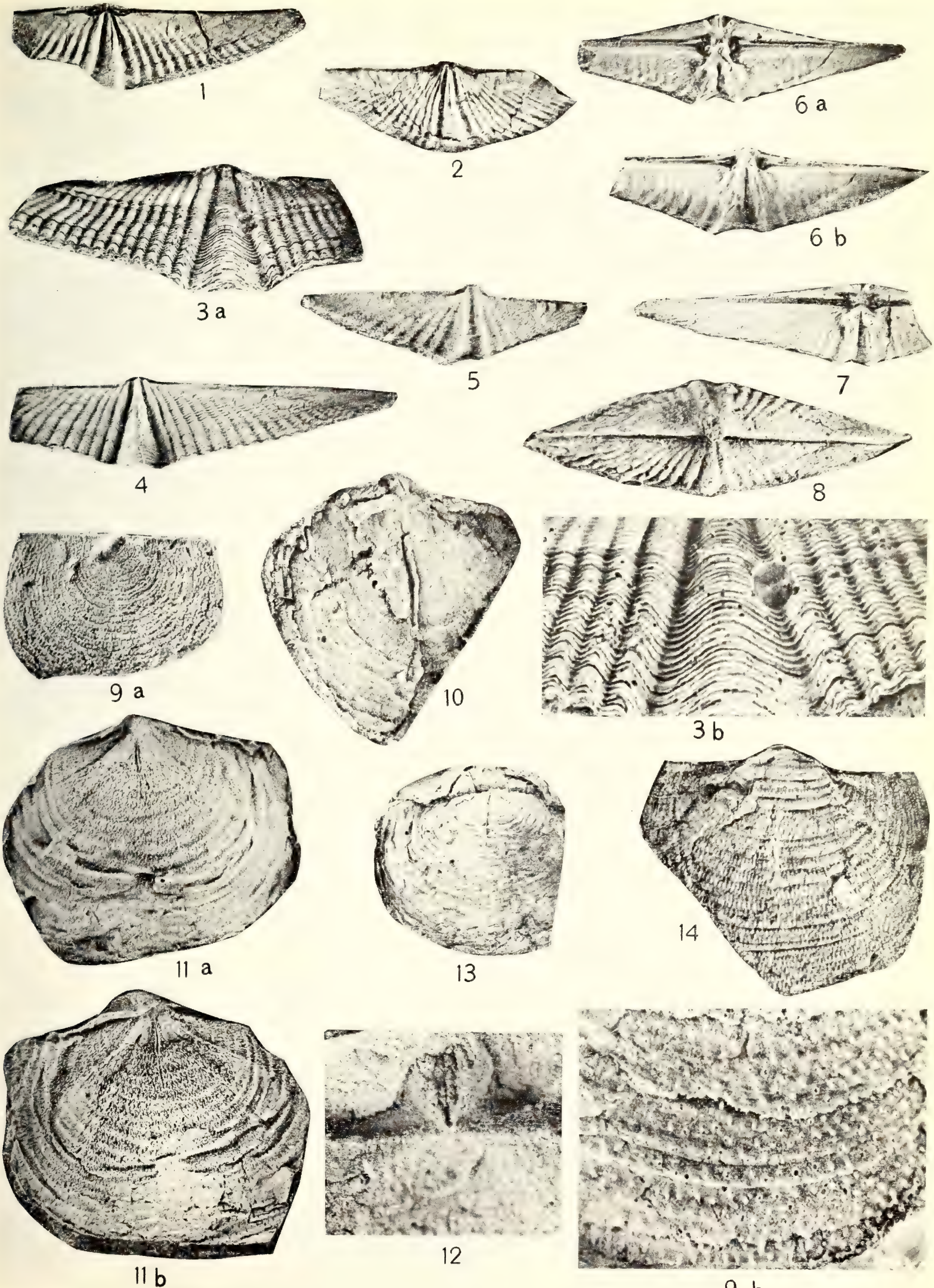
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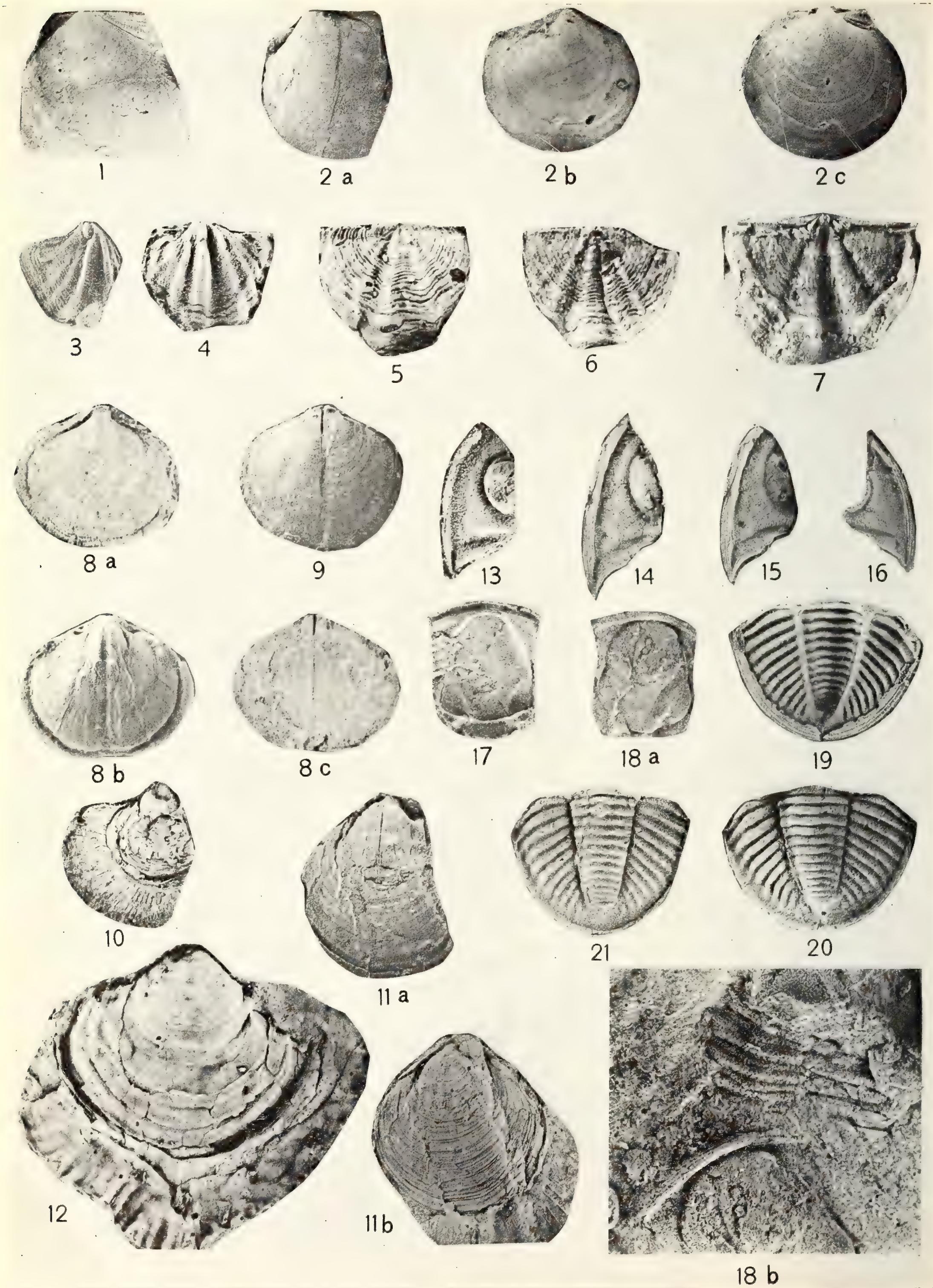
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VOLUME 97 1964 PART 2

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Journal and Proceedings, Royal Society of New South Wales, Vol. 97, pp. 33–40, 1964

Minor Planets Observed at Sydney Observatory During 1962

W. H. Robertson
Sydney Observatory, Sydney

The following observations of minor planets were made photographically at Sydney Observatory with the 9-inch Taylor, Taylor and Hobson lens. Observations were confined to those with southern declinations in the *Ephemerides of Minor Planets* published by the Institute of Theoretical Astronomy at Leningrad.

On each plate two exposures, separated in declination by approximately 0′·5, were taken with an interval of about 20 minutes between them. The beginnings and endings of the exposures were automatically recorded on a chronograph by a contact on the shutter.

Rectangular coordinates of both images of the minor planet and three reference stars were measured in direct and reversed positions of the plate on a long screw measuring machine. The usual three star dependence reduction retaining second order terms in the differences of the equatorial coordinates was used. Proper motions, when they were available, were applied to bring the star positions to the epoch of the plate. Each exposure was reduced separately in order to provide a check by comparing the difference between the two positions with the motion derived from the ephemeris. The tabulated results are means of the two positions at the average time except in cases 1329, 1335, 1365, 1380, 1413, 1421, 1444, 1456, 1457, 1497, 1505, where each result is from only one image, due to a defect in the other exposure or a failure in timing it. No correction has been applied for aberration, light time or parallax but in Table I are given the factors which give the parallax correction when divided by the distance. The serial numbers follow on those of a previous paper (Robertson, 1963). The observers named in Table II are W. H. Robertson (R), K. P. Sims (S) and H. W. Wood (W). The measurements were made by Miss J. Hawkes and Mrs. Y. Lake, who have also assisted in the computation.

Reference

Robertson, W. H., 1963. *J. Proc. Roy. Soc. N.S.W.*, **96**, 31. *Sydney Observatory Papers*, **43**.

Table I

No.	Planet	U.T.			R.A. (1950·0)	Dec. (1950·0)	Parallax Factors	
					h m s	° ′ ″	s	″
1313	10	1962	Sep	13·53692	21 49 10·34	−08 43 15·0	+0·08	−3·7
1314	63	1962	Jul	25·64690	21 27 06·45	−20 16 51·3	+0·04	−2·1
1315	63	1962	Aug	16·60637	21 04 49·68	−20 37 50·8	+0·15	−2·1
1316	88	1962	Mar	20·68292	13 45 46·80	−18 49 38·2	+0·07	−2·3
1317	88	1962	Apr	18·57056	13 23 42·30	−17 02 22·0	+0·01	−2·5
1318	104	1962	Jun	28·62110	19 23 02·34	−25 38 25·4	0·00	−1·2
1319	105	1962	Mar	01·56961	11 06 17·30	−10 04 41·6	−0·10	−3·5
1320	105	1962	Mar	26·53638	10 47 43·32	−03 00 35·2	+0·05	−4·5
1321	106	1962	Apr	30·56138	14 04 42·34	−09 29 56·6	0·00	−3·6
1322	110	1962	Sep	10·63208	00 31 51·57	−05 38 09·5	0·00	−4·1
1323	110	1962	Oct	24·52727	23 58 02·95	−07 37 00·5	+0·12	−3·9
1324	114	1962	May	08·60665	15 29 19·80	−11 13 47·2	+0·03	−3·4
1325	114	1962	May	22·61427	15 17 11·84	−10 19 48·9	+0·19	−3·6
1326	115	1962	Apr	18·69160	15 37 41·15	−36 29 56·4	+0·12	+0·3
1327	115	1962	May	22·55458	15 02 08·99	−35 02 57·8	+0·05	+0·2
1328	128	1962	May	31·70325	18 23 00·54	−24 58 05·2	+0·16	−1·5
1329	128	1962	Jun	21·61164	18 04 52·41	−25 50 36·1	+0·09	−1·2
1330	134	1962	Apr	26·62790	15 09 28·21	−33 47 57·6	+0·04	0·0
1331	134	1962	May	23·55737	14 41 00·02	−32 49 16·3	+0·10	−0·2
1332	135	1962	Jun	28·66680	19 44 29·32	−25 15 41·4	+0·11	−1·4
1333	135	1962	Jul	18·57638	19 26 32·40	−25 41 36·4	+0·03	−1·3
1334	138	1962	May	30·50555	14 43 45·75	−15 47 03·9	0·00	−2·7
1335	138	1962	May	31·48403	14 42 59·82	−15 45 15·3	−0·06	−2·7
1336	160	1962	Mar	26·60086	12 41 51·08	−04 32 30·9	0·00	−4·3

TABLE I—*continued*

No.	Planet	U.T.			R.A. (1950·0)	Dec. (1950·0)	Parallax Factors	
					h m s	° ′ ″	s	″
1337	160	1962	Apr	25·52688	12 18 22·46	−02 40 20·5	+0·08	−4·5
1338	172	1962	Mar	27·67320	14 04 44·22	−26 10 07·3	+0·06	−1·2
1339	172	1962	Apr	25·56530	13 35 51·14	−25 49 15·4	+0·03	−1·2
1340	185	1962	Oct	23·65597	03 25 38·66	−16 50 22·5	+0·07	−2·6
1341	185	1962	Nov	05·56740	03 16 10·02	−18 44 20·3	−0·08	−2·3
1342	186	1962	May	23·64647	17 34 18·53	−43 22 45·9	+0·01	+1·5
1343	186	1962	Jun	21·54591	16 57 48·10	−45 23 12·3	+0·03	+1·8
1344	192	1962	May	15·62918	16 20 37·86	−32 16 59·7	+0·05	−0·2
1345	192	1962	Jun	21·51152	15 40 52·03	−30 31 52·8	+0·09	−0·5
1346	201	1962	Jul	17·54198	18 22 38·50	−15 21 27·5	+0·05	−2·8
1347	240	1962	Jul	24·60273	20 21 38·82	−19 53 57·1	+0·04	−2·1
1348	240	1962	Aug	01·60034	20 14 07·19	−20 24 17·5	+0·12	−2·1
1349	246	1962	Sep	27·65148	02 02 56·44	−02 44 08·0	+0·01	−4·5
1350	246	1962	Oct	23·59432	01 44 08·83	−06 34 25·2	+0·09	−4·0
1351	250	1962	Jun	14·62985	18 28 01·72	−39 42 12·7	+0·04	+0·9
1352	250	1962	Jul	26·47960	17 51 05·66	−39 43 22·9	−0·01	+0·9
1353	253	1962	Jul	04·62970	19 38 35·36	−09 09 08·7	+0·04	−3·6
1354	258	1962	Apr	30·52480	13 36 03·92	−09 00 32·0	−0·05	−3·7
1355	266	1962	May	03·64952	15 37 45·92	−20 40 08·7	+0·10	−2·0
1356	266	1962	May	23·58678	15 21 11·98	−18 34 56·4	+0·11	−2·3
1357	278	1962	Aug	09·66208	22 48 06·32	−20 11 23·2	+0·05	−2·1
1358	278	1962	Aug	22·65272	22 37 46·62	−21 23 35·8	+0·15	−2·0
1359	335	1962	Sep	27·57819	23 52 23·78	−05 58 28·9	+0·06	−4·1
1360	357	1962	Jun	25·62736	19 04 06·84	−09 26 18·3	+0·04	−3·6
1361	357	1962	Jul	25·52847	18 41 35·05	−11 41 25·4	+0·03	−3·3
1362	358	1962	Apr	30·56138	14 04 18·46	−08 58 36·7	0·00	−3·7
1363	360	1962	May	31·62616	17 11 08·32	−09 04 01·9	+0·06	−3·7
1364	360	1962	Jul	04·47665	16 45 49·14	−09 33 57·9	−0·06	−3·6
1365	380	1962	Aug	28·62961	23 09 10·01	−15 50 49·5	+0·06	−2·7
1366	380	1962	Sep	11·57681	22 57 55·31	−17 16 03·6	+0·04	−2·5
1367	382	1962	Aug	30·52006	21 21 01·93	−13 34 21·6	−0·03	−3·0
1368	382	1962	Sep	04·51769	21 17 39·24	−13 41 30·8	+0·01	−3·0
1369	385	1962	May	23·64647	17 41 15·95	−43 55 43·2	−0·01	+1·6
1370	385	1962	Jun	21·54591	17 09 32·34	−43 48 57·5	−0·01	+1·5
1371	393	1962	Mar	06·60456	11 14 06·70	−10 55 39·7	+0·03	−3·4
1372	393	1962	Apr	03·53210	10 53 02·46	−07 08 29·5	+0·09	−3·9
1373	394	1962	May	24·63622	17 34 25·12	−24 48 15·0	−0·02	−1·4
1374	394	1962	Jul	03·53282	16 57 07·78	−25 59 40·2	+0·09	−1·2
1375	395	1962	Apr	30·69542	16 19 26·62	−23 31 58·4	+0·14	−1·7
1376	395	1962	May	29·60780	15 55 55·78	−21 57 06·0	+0·16	−1·9
1377	400	1962	May	02·60807	14 34 32·60	−31 53 19·2	+0·11	−0·4
1378	400	1962	May	24·51570	14 16 33·10	−30 27 38·0	+0·04	−0·5
1379	400	1962	May	29·53025	14 13 31·04	−30 02 24·8	+0·15	−0·7
1380	402	1962	Aug	28·62961	23 10 10·90	−15 26 10·0	+0·06	−2·8
1381	402	1962	Sep	11·57681	22 58 49·25	−17 22 01·3	+0·04	−2·5
1382	404	1962	Jun	26·65929	20 17 41·07	−26 47 17·5	−0·02	−1·1
1383	404	1962	Jul	18·60134	19 57 53·91	−30 16 20·0	+0·04	−0·5
1384	412	1962	Jun	21·67651	19 26 58·58	−20 29 21·0	+0·11	−2·1
1385	412	1962	Jul	26·55248	18 56 32·46	−24 08 45·5	+0·09	−1·5
1386	417	1962	Jul	02·59882	18 19 14·51	−13 15 53·2	+0·10	−3·1
1387	417	1962	Jul	24·48478	18 03 10·60	−13 43 38·7	−0·03	−3·0
1388	418	1962	May	24·59668	16 17 34·49	−22 05 17·2	+0·03	−1·8
1389	418	1962	Jun	13·52664	15 59 21·06	−20 29 55·3	+0·02	−2·0
1390	419	1962	Mar	12·56751	11 42 29·26	−03 53 41·9	−0·09	−4·4
1391	419	1962	Mar	26·57068	11 30 02·32	−02 19 50·6	+0·06	−4·6
1392	422	1962	May	08·64044	16 30 31·23	−28 47 27·5	0·00	−0·7
1393	422	1962	May	31·58616	16 04 47·03	−28 52 34·4	+0·09	−0·8
1394	425	1962	May	03·64952	15 42 20·86	−18 39 39·8	+0·09	−2·3
1395	425	1962	May	23·58678	15 24 58·69	−18 08 12·2	+0·10	−2·4
1396	438	1962	Apr	30·69542	16 16 42·06	−22 43 50·8	+0·14	−1·8
1397	438	1962	May	29·60780	15 49 08·87	−23 19 10·2	+0·17	−1·7
1398	443	1962	Apr	30·56138	14 00 46·87	−06 57 26·6	+0·01	−3·9
1399	451	1962	Jul	16·65634	21 19 42·90	−29 46 21·1	+0·01	−0·6
1400	451	1962	Aug	16·58436	20 55 11·52	−33 09 23·9	+0·12	−0·2
1401	458	1962	Aug	29·65035	23 36 33·36	−13 23 16·9	+0·07	−3·1

TABLE I—*continued*

No.	Planet	U.T.			R.A. (1950·0)			Dec. (1950·0)			Parallax Factors	
					h	m	s	°	′	″	s	″
1402	458	1962	Sep	04·64042	23	32	55·72	−14	25	06·0	+0·10	−3·0
1403	465	1962	May	29·70252	18	06	05·64	−28	18	00·1	+0·18	−1·0
1404	465	1962	May	31·67099	18	04	40·81	−28	16	49·5	+0·10	−0·9
1405	465	1962	Jun	25·58743	17	43	10·01	−27	39	32·0	+0·09	−1·0
1406	478	1962	May	03·64952	15	35	17·73	−20	06	59·8	+0·11	−2·1
1407	478	1962	May	23·58678	15	19	38·22	−17	58	48·1	+0·12	−2·4
1408	483	1962	Sep	27·61759	01	01	38·47	−01	37	52·8	+0·03	−4·7
1409	483	1962	Oct	22·55965	00	46	32·85	−04	58	30·8	+0·10	−4·3
1410	498	1962	Aug	23·67278	23	32	42·20	−20	17	41·3	+0·10	−2·1
1411	498	1962	Sep	03·58491	23	25	55·24	−21	54	23·3	−0·07	−1·8
1412	498	1962	Sep	13·58162	23	18	32·95	−23	01	28·4	+0·03	−1·6
1413	501	1962	Aug	02·63469	22	19	13·39	−33	06	45·4	−0·05	−0·1
1414	501	1962	Aug	28·55115	21	51	12·13	−32	30	11·5	−0·02	−0·2
1415	510	1962	Apr	27·66615	16	03	58·06	−13	06	41·7	+0·04	−3·1
1416	510	1962	May	15·59871	15	50	57·20	−10	31	10·2	+0·01	−3·5
1417	522	1962	Jun	05·59734	17	16	04·78	−19	05	41·6	+0·01	−2·2
1418	522	1962	Jun	28·52084	16	59	46·33	−19	03	59·2	0·00	−2·2
1419	528	1962	Jul	25·60708	20	25	06·21	−36	37	22·3	+0·06	+0·4
1420	528	1962	Aug	20·51770	20	04	46·09	−37	13	37·9	+0·05	+0·5
1421	546	1962	Aug	02·63469	22	07	20·81	−33	22	46·6	−0·02	−0·1
1422	546	1962	Aug	28·55115	21	40	08·27	−34	22	11·7	+0·01	+0·1
1423	558	1962	Sep	24·61376	23	58	37·07	−07	57	29·3	+0·13	−3·9
1424	558	1962	Oct	25·46987	23	40	16·56	−10	24	03·6	−0·01	−3·5
1425	566	1962	Jul	25·64690	21	25	45·77	−20	56	45·4	+0·05	−2·0
1426	566	1962	Aug	22·55234	21	05	36·24	−22	46	17·8	+0·04	−1·7
1427	570	1962	Jul	26·63508	21	23	34·86	−12	41	14·3	+0·02	−3·2
1428	570	1962	Aug	29·52287	21	00	17·05	−14	28	07·1	+0·01	−2·9
1429	579	1962	Sep	26·64908	01	36	07·50	−06	39	19·8	+0·05	−4·0
1430	579	1962	Nov	05·48034	01	05	43·27	−08	05	26·0	−0·07	−3·8
1431	584	1962	Apr	18·60004	14	05	05·34	−28	51	56·6	+0·02	−0·7
1432	584	1962	May	03·53726	13	49	50·37	−27	23	08·1	−0·02	−1·0
1433	596	1962	May	29·70252	18	04	36·27	−27	58	50·5	+0·18	−1·1
1434	596	1962	May	31·67099	18	03	05·98	−28	13	37·1	+0·10	−0·9
1435	599	1962	Jul	17·66160	20	55	34·96	−49	12	12·4	+0·13	+2·3
1436	599	1962	Aug	16·54900	20	26	32·31	−50	59	07·5	+0·09	+2·6
1437	607	1962	Feb.	28·65294	12	25	01·10	−18	35	48·7	−0·02	−2·3
1438	618	1962	Jul	05·63130	19	34	35·40	−20	39	54·5	+0·07	−2·0
1439	618	1962	Jul	25·56943	19	18	22·70	−22	54	49·0	+0·09	−1·7
1440	626	1962	May	03·61435	15	11	53·52	−54	25	07·6	+0·08	+3·1
1441	626	1962	May	24·55219	14	40	39·73	−54	02	00·3	+0·16	+2·9
1442	628	1962	Jun	14·60120	17	38	54·22	−14	11	55·5	+0·05	−2·9
1443	628	1962	Jul	12·51044	17	14	39·62	−16	20	36·0	+0·05	−2·6
1444	638	1962	Aug	28·57966	22	18	53·69	−20	07	27·5	+0·01	−2·1
1445	638	1962	Sep	04·59868	22	13	07·17	−20	45	13·7	+0·15	−2·1
1446	640	1962	Apr	25·63471	15	12	52·17	−21	18	35·2	+0·04	−1·9
1447	640	1962	May	30·50555	14	48	10·87	−17	13	25·2	−0·01	−2·5
1448	666	1962	Jun	25·62736	19	00	21·46	−11	33	54·8	+0·04	−3·3
1449	666	1962	Jul	25·52847	18	32	37·59	−11	40	27·1	+0·05	−3·3
1450	674	1962	Jul	24·66896	21	06	19·52	−35	11	06·1	+0·02	+0·2
1451	674	1962	Aug	07·61166	20	53	33·35	−36	14	15·9	+0·14	+0·3
1452	674	1962	Aug	20·56056	20	41	55·56	−36	44	49·2	+0·11	+0·4
1453	675	1962	May	23·61621	15	43	28·50	−25	28	25·5	+0·16	−1·4
1454	675	1962	Jun	05·51301	15	32	32·13	−24	23	05·3	−0·04	−1·4
1455	684	1962	Jul	04·70973	20	32	48·14	−25	15	11·0	+0·19	−1·5
1456	684	1962	Jul	26·58690	20	11	08·36	−25	47	13·8	+0·03	−1·2
1457	684	1962	Aug	02·57037	20	03	51·07	−25	48	56·0	+0·06	−1·2
1458	704	1962	Apr	18·69160	15	42	21·35	−37	45	03·2	+0·12	+0·6
1459	704	1962	May	22·58916	15	14	01·68	−35	46	27·0	+0·15	+0·2
1460	712	1962	Apr	25·63471	15	10	31·73	−19	35	52·8	+0·05	−2·1
1461	712	1962	May	30·50555	14	41	42·50	−15	35	06·8	0·00	−2·7
1462	722	1962	Aug	28·65168	00	04	59·31	−10	13	28·6	+0·01	−3·5
1463	722	1962	Sep	24·58029	23	38	49·00	−11	49	19·1	+0·07	−3·3
1464	740	1962	May	31·62616	17	02	27·49	−11	32	47·5	+0·08	−3·3
1465	740	1962	Jun	14·56922	16	50	48·13	−11	49	54·6	+0·05	−3·3
1466	742	1962	Jul	04·59743	18	24	57·55	−32	53	21·2	+0·12	−0·2

TABLE I—*continued*

No.	Planet	U.T.			R.A. (1950·0)	Dec. (1950·0)	Parallax Factors	
					h m s	° ′ ″	s	″
1467	742	1962	Jul	24·51924	18 07 52·00	−33 36 10·7	+0·08	0·0
1468	757	1962	May	29·66508	18 01 38·44	−34 33 22·6	+0·07	+0·1
1469	757	1962	Jun	28·56476	17 27 45·85	−35 20 27·0	+0·09	+0·2
1470	760	1962	Jul	05·59272	18 35 52·22	−38 16 39·5	+0·09	+0·7
1471	760	1962	Jul	26·51375	18 17 41·39	−37 14 00·1	+0·06	+0·5
1472	762	1962	May	29·66508	17 58 41·01	−36 07 30·2	+0·08	+0·3
1473	762	1962	Jun	28·56476	17 31 24·49	−35 04 54·9	+0·08	+0·2
1474	767	1962	Jun	28·62110	19 16 49·06	−23 48 41·5	+0·02	−1·5
1475	767	1962	Jul	26·55248	18 53 30·97	−24 46 41·7	+0·10	−1·4
1476	771	1962	Feb	28·61514	10 51 00·79	−14 33 48·0	+0·07	−2·9
1477	771	1962	Mar	27·52647	10 32 15·56	−09 41 13·7	+0·06	−3·6
1478	776	1962	Sep	06·63672	00 35 35·80	−28 27 33·2	−0·03	−0·8
1479	776	1962	Sep	13·61898	00 30 34·39	−29 14 48·4	−0·02	−0·7
1480	820	1962	Aug	29·56401	21 52 52·20	−17 35 08·1	+0·03	−2·5
1481	872	1962	Apr	30·56138	14 04 12·93	−08 08 49·3	0·00	−3·7
1482	877	1962	Sep	06·60010	22 52 10·75	−13 13 29·9	+0·08	−3·2
1483	877	1962	Sep	26·52085	22 37 05·20	−15 02 54·5	+0·04	−2·8
1484	893	1962	Sep	24·65108	00 45 50·11	−13 53 28·6	+0·02	−3·0
1485	906	1962	Sep	03·64606	00 59 19·53	−06 23 14·8	+0·08	−4·1
1486	906	1962	Sep	26·61514	00 41 58·64	−07 20 45·0	+0·06	−3·9
1487	926	1962	May	03·64952	15 36 55·75	−20 06 58·9	+0·11	−2·1
1488	926	1962	May	31·53048	15 08 32·96	−22 06 58·2	+0·03	−1·8
1489	952	1962	Jul	24·64392	21 06 49·98	−33 08 44·1	+0·08	−0·1
1490	952	1962	Aug	02·60569	20 58 19·37	−33 37 08·7	+0·05	0·0
1491	968	1962	Mar	01·60710	11 16 09·67	−08 51 57·3	0·00	−3·7
1492	972	1962	May	08·68138	16 35 52·03	−29 18 49·4	+0·13	−0·8
1493	972	1962	Jun	05·55223	16 12 20·40	−28 00 03·5	0·00	−0·9
1494	975	1962	Aug	30·64150	23 45 36·20	−04 50 07·8	+0·03	−4·3
1495	976	1962	Mar	12·63746	12 34 59·83	−14 32 49·2	+0·01	−2·9
1496	976	1962	Mar	27·59414	12 24 48·79	−13 22 34·9	+0·03	−3·0
1497	1005	1962	Aug	28·57966	22 22 44·32	−20 09 37·6	0·00	−2·1
1498	1005	1962	Sep	04·59868	22 15 53·10	−20 02 05·1	+0·14	−2·2
1499	1018	1962	Jul	26·67080	21 59 24·01	−24 19 22·1	+0·06	−1·4
1500	1018	1962	Aug	27·55078	21 31 19·31	−23 59 41·4	+0·02	−1·5
1501	1021	1962	Jul	02·59882	18 16 30·28	−15 05 57·8	+0·11	−2·9
1502	1021	1962	Jul	25·49035	17 56 49·69	−16 59 50·4	+0·01	−2·5
1503	1034	1962	Jul	24·60273	20 22 11·17	−19 54 05·8	+0·04	−2·1
1504	1034	1962	Aug	01·60034	20 15 21·93	−19 34 43·7	+0·12	−2·2
1505	1034	1962	Aug	23·49710	20 02 47·03	−18 28 24·5	+0·01	−2·3
1504	1069	1962	Jun	25·62736	18 55 38·28	−09 22 19·1	+0·05	−3·6
1507	1069	1962	Jul	25·52847	18 33 31·29	−11 22 30·3	+0·05	−3·3
1508	1096	1962	Oct	25·60152	01 49 11·18	−03 15 06·7	+0·12	−4·5
1509	1096	1962	Nov	05·52467	01 39 25·20	−03 08 48·5	−0·01	−4·5
1510	1196	1962	Aug	22·69585	23 03 50·40	−33 05 24·4	+0·26	−0·5
1511	1196	1962	Sep	27·54273	22 38 20·09	−36 48 24·9	+0·13	+0·4
1512	1200	1962	Jun	05·59734	17 13 11·29	−17 18 12·0	+0·01	−2·5
1513	1200	1962	Jun	28·52084	16 55 20·00	−16 39 08·9	+0·01	−2·6
1514	1245	1962	Jul	04·66823	20 06 18·64	−17 26 45·4	+0·11	−2·5
1515	1245	1962	Aug	07·55856	19 38 56·69	−19 10 45·1	+0·12	−1·8
1516	1382	1962	Apr	30·69542	16 16 34·51	−24 02 24·0	+0·14	−1·5
1517	1382	1962	May	29·60780	15 50 20·02	−23 17 41·0	+0·17	−1·7
1518	1424	1962	Jul	04·59743	18 22 14·41	−34 18 09·5	+0·13	0·0
1519	1426	1962	May	02·60807	14 48 39·53	−32 38 51·0	+0·08	−0·2
1520	1585	1962	Aug	27·61893	23 12 06·67	−13 20 19·2	+0·01	−3·1
1521	1585	1962	Aug	30·60421	23 10 17·56	−14 13 24·6	−0·01	−3·0
1522	1594	1962	May	31·67099	18 07 57·85	−26 55 28·5	+0·09	−1·1
1523	1603	1962	Aug	29·56401	21 48 37·57	−17 47 38·2	+0·04	−2·4
1524	1603	1962	Sep	03·52747	21 44 57·63	−18 20 42·1	+0·03	−2·3
1525	1607	1962	Jul	03·65329	19 00 17·67	−16 53 07·9	+0·19	−2·7
1526	1607	1962	Jul	24·55847	18 40 11·36	−19 18 58·9	+0·12	−2·3
1527	1607	1962	Jul	30·52903	18 35 30·81	−20 03 04·7	+0·09	−2·1
1528	1941 UF	1962	Aug	27·65989	00 00 50·93	−04 32 34·3	+0·03	−4·3
1529	1962 QK	1962	Aug	30·56112	22 10 21·21	−32 25 23·6	−0·01	−0·2
1530	1962 QK	1962	Sep	06·55162	22 04 47·87	−33 11 44·0	+0·04	−0·1

TABLE II

No.	Comparison Stars	Dependences			
1313	Yale *16* 7845, 7847, 7861	0·26844	0·34186	0·38970	W
1314	Yale *13* I 9190, 9201, 9215	0·25206	0·45340	0·29454	S
1315	Yale *13* I 9048, 9052, 9073	0·46591	0·20490	0·32919	S
1316	Yale *12* II 5824, 5831, 5846	0·32376	0·37177	0·30447	S
1317	Yale *12* I 5073, 5088, 5094	0·36123	0·31545	0·32332	W
1318	Yale *14* 13500, 13527, 13535	0·15357	0·36492	0·48151	R
1319	Yale *11* 4194, *16* 4199, 4222	0·37089	0·52265	0·10646	S
1320	Yale *17* 4126, 4139, 4152	0·36075	0·24804	0·39121	W
1321	Yale *16* 5001, 5013, 5014	0·39426	0·12581	0·47993	S
1322	Yale *16* 98, 105, 116	0·22638	0·40442	0·36920	W
1323	Yale *16* 8437, 8457, 8462	0·41098	0·35094	0·23808	W
1324	Yale *11* 5407, 5430, 5432	0·35819	0·14403	0·49778	W
1325	Yale *16* 5348, *11* 5355, 5373	0·55780	0·22447	0·21773	S
1326	Cape *18* 7704, 7741, 7746	0·23505	0·43934	0·32560	W
1327	Cape *18* 7368, 7397, *17* 7811	0·40150	0·30301	0·29550	S
1328	Yale *14* 12749, 12762, 12790	0·26086	0·37199	0·36715	W
1329	Yale *14* 12464, 12496, 12556	0·37413	0·46991	0·15596	W
1330	Cape *17* 7848, 7888, 7889	0·30991	0·27688	0·41321	R
1331	Cape *17* 7582, 7589, 7605	0·17739	0·40605	0·41656	S
1332	Yale *14* 13766, 13791, 13798	0·27109	0·23792	0·49099	R
1333	Yale *14* 13561, 13565, 13576	0·40974	0·38246	0·20780	R
1334	Yale *12* I 5430, 5456, 5459	0·15595	0·53426	0·30979	W
1335	Yale *12* I 5439, 5447, 5456	0·10343	0·49645	0·40012	W
1336	Yale *17* 4664, 4665, 4674	0·21321	0·54221	0·24457	W
1337	Yale *17* 4551, 4554, 4563	0·17411	0·24041	0·58548	R
1338	Yale *14* 10236, 10247, 10280	0·37842	0·28076	0·34082	W
1339	Yale *14* 10011, 10015, 10021	0·56441	0·24782	0·18777	R
1340	Yale *12* I 913, 916, 920	0·52470	0·31520	0·16009	W
1341	Yale *12* II 907, 913, 929	0·10239	0·44092	0·45669	S
1342	Cord. D 12628, 12692, 12701	0·31950	0·30133	0·37917	S
1343	Cord. D 11995, 12019, 12092	0·35267	0·38095	0·26639	W
1344	Cape *17* 8524, 8535, 8564	0·39361	0·27036	0·33603	R
1345	Cape *17* 8113, 8138, 8151	0·35759	0·35491	0·28751	W
1346	Yale *12* I 6725, 6748, 6750	0·19773	0·36474	0·43753	R
1347	Yale *13* I 8732, 8738, 8768	0·48424	0·20519	0·31056	S
1348	Yale *13* I 8670, 8676, 8709	0·36464	0·29117	0·34420	W
1349	Yale *17* 491, 494, 509	0·42435	0·31090	0·26474	S
1350	Yale *16* 359, 363, 378	0·13514	0·47907	0·38579	W
1351	Cape *18* 9521, 9531, 9534	0·10869	0·30121	0·59009	S
1352	Cape *18* 9058, 9067, 9119	0·43590	0·31726	0·24684	W
1353	Yale *16* 6854, 6882, 6883	0·28022	0·35870	0·36108	S
1354	Yale *16* 4849, 4864, 4877	0·27924	0·38227	0·33849	S
1355	Yale *13* I 6471, 6485, *12* II 6500	0·28070	0·51863	0·20067	S
1356	Yale *12* II 6348, 6371, 6374	0·18593	0·46195	0·35212	S
1357	Yale *13* I 9613, 9638, 9651	0·35247	0·31838	0·32915	R
1358	Yale *13* I 9569, 9589, *14* 15319	0·36195	0·42849	0·20956	W
1359	Yale *16* 8413, 8432, *17* 8166	0·18649	0·54185	0·27166	S
1360	Yale *16* 6553, 6561, 6593	0·32642	0·41666	0·25692	R
1361	Yale *11* 6409, 6419, 6434	0·22162	0·51925	0·25912	S
1362	Yale *16* 5000, 5007, 5013	0·34377	0·23348	0·42275	S
1363	Yale *16* 5859, 5869, 5875	0·32498	0·62991	0·04510	W
1364	Yale *16* 5777, 5788, 5790	0·12571	0·61646	0·25782	R
1365	Yale *12* I 8570, 8576, 8600	0·22851	0·53195	0·23954	R
1366	Yale *12* I 8517, 8537, 8542	0·39127	0·30464	0·30408	W
1367	Yale *11* 7574, 7580, *12* I 8068	0·37551	0·25613	0·36836	R
1368	Yale *12* I 8032, *11* 7559, 7574	0·28938	0·35691	0·35370	S
1369	Cord. D 12747, 12829, 12867	0·23231	0·61489	0·15280	S
1370	Cord. D 12198, 12236, 12260	0·25761	0·40938	0·33302	W
1371	Yale *11* 4225, 4240, 4248	0·48954	0·23142	0·27904	W
1372	Yale *16* 4129, 4140, 4154	0·22581	0·55274	0·22144	R
1373	Yale *14* 12076, 12111, 12113	0·46763	0·33193	0·20044	S
1374	Yale *14* 11737, 11743, 11771	0·28428	0·38280	0·33292	S
1375	Yale *14* 11423, 11450, 11462	0·22414	0·19819	0·57767	S
1376	Yale *13* I 6587, 6606, 6608	0·45748	0·18929	0·35322	W
1377	Cape *17* 7512, 7532, 7545	0·14714	0·45177	0·40109	S
1378	Cape *17* 7333, 7348, 7357	0·41430	0·31249	0·27321	S

TABLE II—*continued*

No.	Comparison Stars	Dependences			
1379	Yale *13* II 8993, 9020, 9028	0·21593	0·36123	0·42284	W
1380	Yale *12* I 8570, 8576, 8600	0·37937	0·06793	0·55270	R
1381	Yale *12* I 8517, 8537, 8542	0·23672	0·22058	0·54269	W
1382	Yale *14* 14087, 14139, *13* II 13392	0·19982	0·28762	0·51256	R
1383	Cape *17* 10886, 10898, 10916	0·21097	0·40675	0·38228	R
1384	Yale *13* I 8316, 8332, 8356	0·30196	0·19033	0·50772	W
1385	Yale *14* 13169, 13205, 13211	0·27955	0·52021	0·20024	S
1386	Yale *11* 6240, 6265, 6277	0·19286	0·53622	0·27092	S
1387	Yale *11* 6146, 6164, 6174	0·11540	0·54642	0·33818	W
1388	Yale *13* I 6733, 6756, *14* 11443	0·20764	0·25915	0·53320	S
1389	Yale *13* I 6601, 6638, *12* II 6621	0·46833	0·31842	0·21325	S
1390	Yale *17* 4391, 4410, 4416	0·42766	0·29861	0·27372	R
1391	Yale *21* 3263, 3270, *17* 4329	0·14753	0·46121	0·39126	W
1392	Yale *13* II 10339, 10347, 10390	0·37241	0·32954	0·29806	W
1393	Yale *13* II 10094, 10118, 10119	0·31072	0·33894	0·35034	W
1394	Yale *12* II 6499, 6517, 6521	0·35697	0·33134	0·31169	S
1395	Yale *12* I 5668, 5671, 5684	0·40992	0·34377	0·24630	S
1396	Yale *14* 11423, 11431, 11452	0·43423	0·33327	0·23250	S
1397	Yale *14* 11161, 11181, 11201	0·36037	0·51950	0·12013	W
1398	Yale *16* 4977, 4990, 4998	0·27607	0·54534	0·17859	S
1399	Yale *13* II 14012, 14050, Cape *17* 11670	0·30186	0·40930	0·28884	R
1400	Cape *17* 11422, 11424, 11469	0·19106	0·38793	0·42101	S
1401	Yale *11* 8233, 8241, *12* I 8723	0·41148	0·26435	0·32416	R
1402	Yale *12* I 8695, 8696, 8714	0·44666	0·12839	0·42495	S
1403	Yale *13* II 11660, 11669, 11731	0·26000	0·19730	0·54270	W
1404	Yale *13* II 11636, 11651, 11713	0·20569	0·33047	0·46384	W
1405	Yale *13* II 11265, 11275, 11303	0·38047	0·35985	0·25968	R
1406	Yale *12* II 6449, 6464, 6471	0·30967	0·28750	0·40283	S
1407	Yale *12* II 6348, 6374, *12* I 5639	0·29402	0·27258	0·43341	S
1408	Yale *17* 229, 243, *21* 203	0·39325	0·37648	0·23027	S
1409	Yale *17* 165, 179, 180	0·33078	0·17194	0·49728	W
1410	Yale *13* I 9847, 9870, 9871	0·50331	0·39716	0·09953	W
1411	Yale *13* I 9819, *14* 15703, 15743	0·43762	0·27782	0·28456	S
1412	Yale *14* 15647, 15655, 15665	0·23447	0·44827	0·31726	W
1413	Cape *17* 12128, 12142, 12149	0·09057	0·23886	0·67058	W
1414	Cape *17* 11909, 11913, 11935	0·21081	0·45688	0·33231	R
1415	Yale *11* 5567, 5587, 5590	0·27939	0·31673	0·40388	R
1416	Yale *11* 5507, 5524, *16* 5526	0·19323	0·47246	0·33431	R
1417	Yale *12* II 7065, 7078, 7079	0·20577	0·26158	0·53265	R
1418	Yale *12* II 6943, 6953, 6959	0·36583	0·36584	0·26833	R
1419	Cape *18* 10597, 10633, 10638	0·48988	0·29584	0·21428	S
1420	Cape *18* 10408, 10422, 10459	0·13088	0·50956	0·35956	W
1421	Cape *17* 12020, 12051, 12060	0·23086	0·52646	0·24268	W
1422	Cape *17* 11818, 11832, 11849	0·25512	0·44950	9·29538	R
1423	Yale *16* 8446, 8449, 8463	0·19573	0·57930	0·22497	S
1424	Yale *11* 8244, 8254, 8255	0·23964	0·46485	0·29551	R
1425	Yale *13* I 9181, 9190, 9214	0·36278	0·33038	0·30684	S
1426	Yale *14* 14585, 14604, 14609	0·22956	0·45924	0·31120	S
1427	Yale *11* 7580, 7611, 7616	0·37582	0·38719	0·23699	S
1428	Yale *12* I 7907, 7930, 7938	0·32122	0·30258	0·37620	R
1429	Yale *16* 329, 332, 341	0·36904	0·28470	0·34626	S
1430	Yale *16* 228, 229, 234	0·45526	0·42231	0·12242	S
1431	Yale *13* II 8907, 8914, 8953	0·38598	0·26717	0·34685	W
1432	Yale *13* II 8766, 8805, *14* 10142	0·44128	0·34666	0·21206	S
1433	Yale *13* II 11660, 11669, 11731	0·25796	0·53626	0·20578	W
1434	Yale *13* II 11636, 11651, 11713	0·38566	0·48073	0·13361	W
1435	Cape Zone 19092, 19108, 19130	0·52471	0·14428	0·33101	R
1436	Cape Zone 18826, 18830, 18867	0·50808	0·27997	0·21194	S
1437	Yale *12* II 5389, 5411, *12* I 4782	0·29535	0·28724	0·41741	S
1438	Yale *13* I 8388, 8398, 8424	0·38768	0·28959	0·32272	S
1439	Yale *14* 13436, 13484, 13485	0·29362	0·36465	0·34173	S
1440	Cape *19* 5774, 5804, 5833	0·33748	0·38464	0·27788	S
1441	Cape *19* 5574, 5583, 5605	0·16647	0·49610	0·33743	S
1442	Yale *11* 6034, *12* I 6346, 6379	0·30995	0·21819	0·47186	S
1443	Yale *12* I 6181, 6195, 6201	0·36670	0·36286	0·27044	W
1444	Yale *13* I 9478, 9489, 9492	0·24578	0·48019	0·27403	R

TABLE II—*continued*

No.	Comparison Stars	Dependences			
1445	Yale *13* I 9450, 9456, 9474	0·40980	0·29210	0·29809	S
1446	Yale *13* I 6313, 6315, 6323	0·64126	0·21144	0·14730	R
1447	Yale *12* I 5461, 5483, 5485	0·16640	0·60006	0·23355	W
1448	Yale *11* 6567, 6581, 6588	0·22790	0·35969	0·41241	R
1449	Yale *11* 6345, 6376, 6382	0·36930	0·46475	0·16595	S
1450	Cape *18* 10906, 10931, 10932	0·30207	0·12209	0·57584	S
1451	Cape *18* 10813, 10823, 10833	0·28183	0·22078	0·49739	R
1452	Cape *18* 10730, 10738, 10760	0·45854	0·16901	0·37244	W
1453	Yale *14* 11101, 11116, 11154	0·29266	0·32910	0·37824	S
1545	Yale *14* 11027, 11028, 11057	0·33096	0·29289	0·37615	R
1455	Yale *14* 14261, 14303, 14318	0·40642	0·28301	0·31057	S
1456	Yale *14* 14043, 14046, 14076	0·40431	0·26926	0·32643	S
1457	Yale *14* 13984, 13985, 14012	0·35297	0·33318	0·31385	W
1458	Cape *18* 7766, 7767, 7793	0·45660	0·25241	0·29099	W
1459	Cape *18* 7498, 7499, 7523	0·41562	0·21812	0·36626	S
1460	Yale *12* II 6294, 6303, 6307	0·43473	0·30927	0·25600	R
1461	Yale *12* I 5430, 5456, 5459	0·49818	0·19873	0·30310	W
1462	Yale *11* 3, 4, 14	0·19762	0·30163	0·50075	R
1463	Yale *11* 8243, 8249, 8258	0·27848	0·59189	0·12962	S
1464	Yale *11* 5831, 5845, 5851	0·25717	0·33220	0·41062	W
1465	Yale *11* 5786, 5791, 5809	0·23085	0·54386	0·22529	S
1466	Cape *17* 9947, 9975, 9983	0·39885	0·19708	0·40407	S
1467	Cape *17* 9729, 9730, 9773	0·27364	0·28025	0·44610	S
1468	Cape *17* 9658, 9660, 9691	0·25119	0·38808	0·36072	W
1469	Cape *18* 8742, 8764, 8784	0·29677	0·26067	0·44256	R
1470	Cape *18* 9579, 9609, 9642	0·24182	0·39096	0·36722	S
1471	Cape *18* 9374, 9410, 9420	0·25979	0·46381	0·27640	S
1472	Cape *18* 9145, 9195, 9202	0·32438	0·30366	0·37196	W
1473	Cape *17* 9292, *18* 8798, 8838	0·49912	0·22835	0·27252	R
1474	Yale *14* 13414, 13445, 13469	0·25343	0·35119	0·39539	R
1475	Yale *14* 13146, 13169, 13178	0·53926	0·27441	0·18632	S
1476	Yale *12* I 4326, 4347, *11* 4109	0·22823	0·23754	0·53423	S
1477	Yale *16* 4013, 4017, 4030	0·27608	0·29788	0·42604	W
1478	Yale *13* II 198, 215, 231	0·35405	0·28831	0·35764	S
1479	Yale *13* II 164, 183, 194	0·41911	0·08285	0·49804	W
1480	Yale *12* II 9343, 9367, *12* I 8213	0·31752	0·42580	0·25669	R
1481	Yale *16* 5000, 5003, 5022	0·25233	0·42224	0·32544	S
1482	Yale *11* 8044, 8057, 8063	0·47558	0·21858	0·30584	S
1483	Yale *12* I 8421, 8434, 8435	0·18252	0·17456	0·64292	S
1484	Yale *12* I 196, 210, *11* 154	0·50268	0·28865	0·20868	S
1485	Yale *16* 197, 211, 213	0·25660	0·34621	0·39719	S
1486	Yale *16* 145, 146, 155	0·20770	0·49348	0·29883	S
1487	Yale *12* II 6464, 6471, 6500	0·27640	0·47396	0·24964	S
1488	Yale *14* 10821, *13* I 6284, 6304	0·24565	0·49052	0·26383	W
1489	Cape *17* 11543, 11553, 11573	0·52036	0·30429	0·17535	S
1490	Cape *17* 11464, 11465, 11506	0·54730	0·23685	0·21585	W
1491	Yale *16* 4249, 4255, 4256	0·18428	0·49749	0·31823	S
1492	Yale *13* II 10399, 10417, 10440	0·37968	0·30724	0·31308	W
1493	Yale *13* II 10181, 10183, 10194	0·20681	0·21303	0·58015	R
1494	Yale *17* 8136, 8141, 8146	0·15011	0·40732	0·44256	R
1495	Yale *12* I 4822, 4842, *11* 4583	0·29495	0·40186	0·30319	R
1496	Yale *11* 4519, 4531, 4535	0·37682	0·29431	0·32887	W
1497	Yale *13* I 9490, 9515, 9516	0·34217	0·37088	0·28694	R
1498	Yale *13* I 9456, 9474, 9482	0·23082	0·32504	0·44414	S
1499	Yale *14* 15032, 15046, 15068	0·34326	0·24379	0·41295	S
1500	Yale *14* 14808, 14836, 14838	0·35050	0·30090	0·34860	R
1501	Yale *12* I 6651, 6673, 6701	0·41409	0·19528	0·39063	S
1502	Yale *12* I 6455, 6470, 6487	0·25637	0·22911	0·51451	S
1503	Yale *13* I 8732, 8738, 8768	0·37942	0·16666	0·45392	S
1504	Yale *12* II 8676, 8692, 8699	0·19311	0·51248	0·29442	W
1505	Yale *12* II 8598, 8600, 8622	0·32052	0·49992	0·17957	W
1506	Yale *16* 6468, 6476, 6495	0·25756	0·50765	0·23478	R
1507	Yale *11* 6345, 6376, 6382	0·21294	0·33461	0·45245	S
1508	Yale *17* 419, 423, 441	0·39866	0·30523	0·29611	W
1509	Yale *17* 383, 396, 402	0·44619	0·26018	0·29362	S
1510	Cape *17* 12462, 12466, 12487	0·25429	0·46191	0·28380	W

TABLE II—*continued*

No.	Comparison Stars	Dependences			
1511	Cape *18* 11610, 11623, 11656	0·20155	0·31924	0·47921	S
1512	Yale *12* I 6157, 6179, 6193	0·17347	0·41965	0·40689	R
1513	Yale *12* I 6047, 6066, 6078	0·18981	0·40656	0·40363	R
1514	Yale *12* I 7562, 7573, *12* II 8620	0·23986	0·41745	0·34269	S
1515	Yale *12* II 8408, 8448, 8450	0·25475	0·13217	0·61308	R
1516	Yale *14* 11418, 11437, 11450	0·46181	0·25273	0·28545	S
1517	Yale *14* 11161, 11181, 11201	0·10414	0·48152	0·41433	W
1518	Cape *17* 9914, 9925, 9955	0·35713	0·42255	0·22032	S
1519	Cape *17* 7647, 7675, 7677	0·22695	0·49603	0·27702	S
1520	Yale *11* 8130, 8155, *12* I 8598	0·40740	0·20238	0·39022	R
1521	Yale *12* I 8577, 8597, 8598	0·51308	0·23006	0·25685	R
1522	Yale *14* 12505, 12570, *13* II 11717	0·27183	0·51876	0·20940	W
1523	Yale *12* II 9323, 9326, 9343	0·43392	0·24065	0·32543	R
1524	Yale *12* II 9298, 9300, 9326	0·38495	0·34645	0·26860	S
1525	Yale *12* I 7044, 7047, 7067	0·68392	0·15558	0·16050	S
1526	Yale *12* II 7840, 7848, 7881	0·32209	0·39896	0·27895	S
1527	Yale *13* I 7797, 7820, 7843	0·50750	0·36605	0·12645	W
1528	Yale *17* 8190, 8191, 9	0·11164	0·43965	0·44872	R
1529	Cape *17* 12061, 12064, 12078	0·28211	0·25984	0·45805	R
1530	Cape *17* 12001, 12021, 12038	0·21024	0·27765	0·51211	S

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Depositional Environments and Provenance of Devonian and Carboniferous Sediments in the Tamworth Trough, N.S.W.

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Abstract—Data from sedimentary structures, sediment textures, chemical characteristics of sediments, and fossils, suggest that much of the Tamworth and Parry Groups accumulated in a turbidity current-dominated environment, probably in deep water. The upper part of the Parry Group and part of the Drik-Drik Formation apparently accumulated in shallow water. Conflicting evidence on depositional environment from the Yarrimie Formation suggests lateral variations in depth of water, with shallow, tranquil conditions in the north and south where coralline limestones and fine terrigenous turbidites coexist. A generalized map shows the various lithosomes and biosomes recognized.

Directional structures in the sediments and isopach data suggest that the Tamworth Trough was elongated along a 340°–160° axis, with a shoreline to the southwest. It appears to have maintained its overall shape throughout the period of sedimentation, deriving most of its sediment from the southwest, a little from the southeast, while more travelled along the axis, from a source at the northeast end of, or marginal to, the trough.

Introduction

The Tamworth Trough sequence in the Tamworth-Nundle district of N.S.W. consists of two major units, the Tamworth and Parry Groups (Crook, 1961*a*, 1961*b*). An outline of their stratigraphic subdivision is given in Table 1.

The former consists of volcanic lithic graywackes (Crook, 1960*a*) and rudites, with appreciable radiolarian cherty argillite in the upper parts. Coralline limestone is developed on two horizons, and penecontemporaneous spilite and keratophyre is locally prominent.

The Parry Group consists chiefly of mudstone with some prominent developments of volcanic lithic graywacke and sandstone (Crook, 1960*b*) and polymictic conglomerate.

Depositional Environments

These two units record a range of depositional and biological environments. Most of the environments appear to have been of deeper water type, but the upper part of the Parry Group apparently records a gradual change to shallower water, passing eventually into terrestrial conditions in the overlying Kuttung " Group ".

Data of environmental significance from the Tamworth Trough sequence are at present rather limited. Several potential sources of information remain uninvestigated, and no source has yet been investigated exhaustively. Sufficient is known, however, to justify a statement of our present understanding of the problem.

Data of significance are available from (*a*) sedimentary structures, (*b*) sediment textures, (*c*) chemical characteristics of the sediments, (*d*) fossils.

Sedimentary Structures

Packham (1954) has recognized two distinct associations of structures which he considers reflect distinct environments, one characterized by traction currents (generally shallow water) and the other by turbidity currents (generally deep water). Lenticular sedimentation units and large-scale cross-stratification are particularly characteristic of traction current deposits. Graded bedding, convolute bedding, pull-aparts, sole markings, and extensive sedimentation units with parallel bounding surfaces are characteristic of turbidity current deposits (turbidites).

The distribution of various types of sedimentary structures in the Tamworth Trough sequence is shown in Table 1. Units including and above the Gowrie Sandstone Member, and including and above Member 7 of the Pyramid Hill Arenite (these being equivalent parts of the sequence), exhibit the characteristics of Packham's traction current deposits. In addition Members 5 and 7 of the Pyramid Hill Arenite exhibit some features of turbidity current deposits, particularly in the finer units. From below Member 7, and below the Gowrie Sandstone Member, to the base of the Yarrimie Formation, the sequence is characterized by structures suggestive of turbidity current activity. Data from older parts of the sequence

TABLE 1

Stratigraphic subdivisions of the Tamworth and Parry Groups

			Eastern and Southern Regions	Western and Northern Regions
Lower Carboniferous	Visean ?		(not preserved)	"Lower Kuttung Group" (CK)
Lower Carboniferous	Tournaisian	P A R R Y G R O U P	Goonoo Goonoo Mudstone (Clg) Pyramid Hill Arenite Members (Clp) -1 -2 -3 -4 -4a -5 -6 -7 P- Q- R- S- T- U- V- Va- W- -8 X- -9 Y- -10 Z- -Benama Graywacke Member (Clbg) -Wombramurra Formation (Clw) -Scrub Mountain Conglomerate Member (Cls) -Hyde Graywacke Member (Clh)	Goonoo Goonoo Mudstone (Clg) -Boiling Down Sandstone Member (Clbs) -Gowrie Sandstone Member (Clgs) -Turi Graywacke Member (Clt) -Garoo Conglomerate Member (Clgc) -Scrub Mountain Conglomerate Member (Cls) -Kiah Limestone Member (Dlk)
Upper Devonian ?		P A R R Y G R O U P	Baldwin Formation (Dub)	Baldwin Formation (Dub)
Middle Devonian		T A M W O R T H G R O U P	Yarrimie Formation (Dmy) Silver Gully Formation (Dms)	Yarrimie Formation including Levy Graywacke Member (Dmlg) Silver Gully Formation (Dms)
Lower Devonian		T A M W O R T H G R O U P	Wogarda Argillite (Dlw) Drik-Drik Formation (Dld) Cope's Creek Keratophyre (Dlc) Pipeclay Creek Formation (Dlp) ------------------------- Hawk's Nest Beds (Dh) (Stratigraphic position unknown)	Seven Mile Formation (Dls)

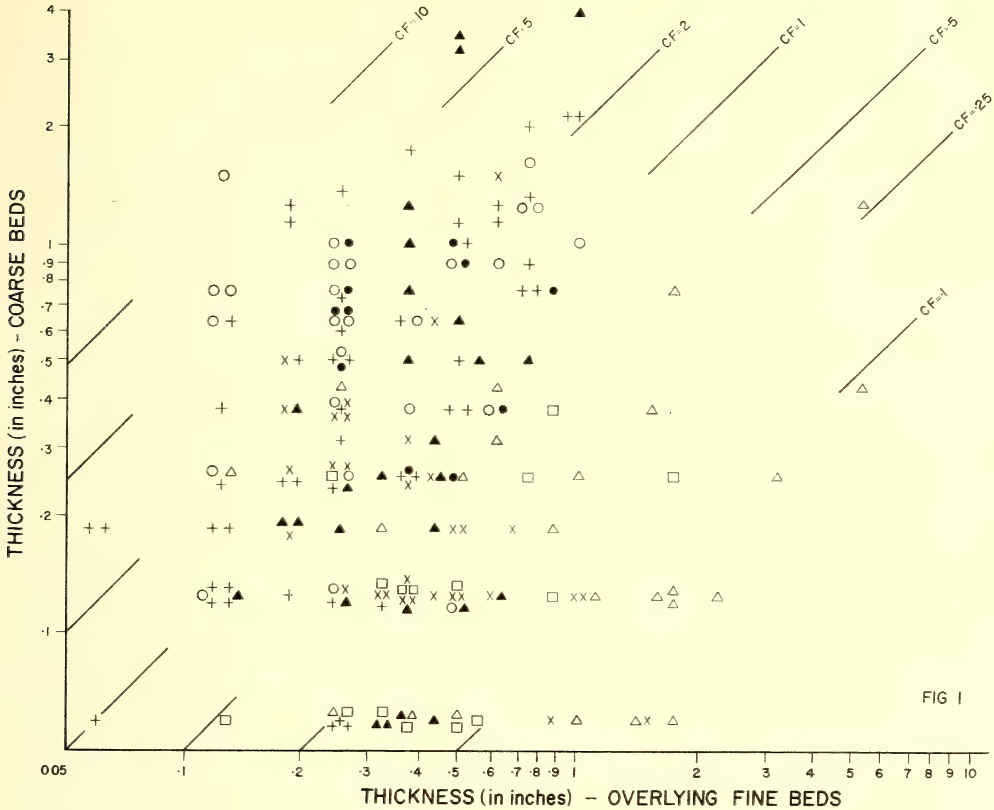


FIG. 1

Plot of thicknesses of paired coarse and fine sedimentation units

Symbols : ○—Locality 1 ; ●—Locality 2 ; ×—Locality 3 ; △—Locality 4 ; □—Locality 5 ; +—Locality 6 ; ▲—Locality 7

Details of Localities in Appendix I

also suggest turbidity current activity but are less definite.

Bed-thickness Data : The mudstones of the Parry Group are characterized by alternating coarse and fine layers. The ratio of the thickness of each coarse layer to the immediately overlying fine layer (the CF ratio) was calculated for several pairs of beds in a series of outcrops. Figure 1 shows variations in the CF ratios. The *mean* CF ratio for successions at various localities ranges from 0·21 to 2·73 (see Appendix I).

The thickness of coarse units increases with increasing CF ratio (Fig. 2). Thus those successions with high *mean* CF ratios will contain relatively more coarse material, in thicker beds, than successions with low mean CF ratios.

If the coarse material is contributed by turbidity currents and the fine by settling from suspension (pelagic sedimentation), the turbidity current contribution will be dominant in those successions with high mean CF ratio. The thicker beds of these successions also imply larger turbidity currents than elsewhere.

It is therefore significant that those successions with high mean CF ratios (>1·0) are in close proximity to conglomerates, while the remainder are remote from conglomerates. One would expect conglomerates in turbidite sequences only where slumping and turbidity current activity were intense.

The relationship between mean CF ratio and turbidity current activity postulated from the above data receives independent support from the distribution of conglomerate units. If the postulate is valid, a broader study of bed-thickness relationships might be expected to yield valuable information on variations of depositional environment.

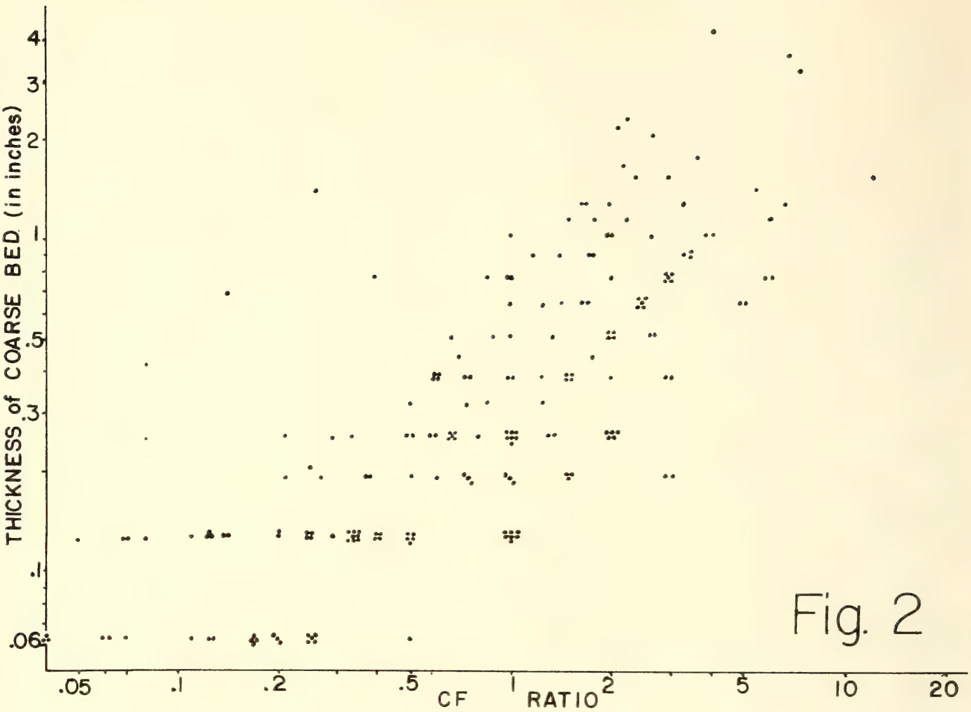


Fig. 2

Plot, for each pair of sedimentation units, of the thickness of the coarse unit vs. the CF ratio of the pair

Sediment Textures

Grainsize: Grainsize distribution features of the Tamworth Trough sediments may be of environmental significance. However, the qualitative data obtained from thin-section study reveal no striking trends. Most arenites are moderately to well sorted, with little matrix (<10%).

Diamictites (Flint, *et al.*, 1960)—" non-sorted, essentially non-calcareous sediments consisting of sand and/or larger particles dispersed through a muddy matrix "—are not common. The most prominent diamictites consist of rounded igneous pebbles and cobbles scattered through a mudstone matrix, which is generally non-laminated. Vertically and laterally, by increase in clast content, the diamictites pass into conglomerates. In the Scrub Mountain Conglomerate Member the diamictites are associated with arenites exhibiting graded bedding and load-cast structures. Mudstones underlying the diamictites, both there and in the Garoo Conglomerate Member, are much disturbed by large-scale slumping.

All the diamictites are in the vicinity of conglomerates, chiefly those of the two members mentioned above. Both are thought, on internal evidence, to be in part the result of submarine slumping (Crook, 1961*b*, p. 201).

In grainsize, sedimentary features, and associations, the diamictites are akin to the pebbly mudstones described by Crowell (1957) from California. An origin by the down-slope slumping of gravel deposited by turbidity currents on water-saturated mud, postulated by Crowell, would hold equally well for the Tamworth Trough examples.

Grain shape: In the lower part of the Drik-Drik Formation, grain shape appears to offer significant information on depositional environment. The keratophyre breccia characteristic of this unit is remarkable in containing clasts up to 5 cm diameter of highly irregular shape and extreme angularity (Crook, 1960*a*). This indicates a negligible distance of fluvial transport, and in conjunction with other features of the unit, suggests a shallow water marine or a terrestrial depositional environment.

Chemical Characteristics

Chemical and biochemical sedimentation was an important factor in the genesis of some parts

of the Tamworth Trough sequence. The Kiah Limestone Member is a slightly recrystallized lithographic limestone (micrite) lacking terrigenous detritus. It is of wide distribution despite its extreme thinness (generally about 3′) (Crook, 1960*b*, 1961*b*), and appears to be of chemical origin. This limestone represents an unusual episode in the history of the trough, in which the supply of terrigenous detritus was temporarily suspended, allowing a purely chemical sediment to accumulate.

Oolites, presumably also of chemical origin, form a minor component in parts of the Drik-Drik Formation (Crook, 1960*a*), and imply a shallow water origin for these rocks.

In the Parry Group and the Yarrimie Formation argillaceous limestone occurs as concretions. Their features, and particularly their poor compaction (Crook, 1960*a*, 1960*b*; 1961*a*, p. 185; 1961*b*, p. 197), suggest that they are of early diagenetic origin and developed close to the water-sediment interface.

The occurrence of these calcareous materials, and of coralline limestones (biolithites and biorudites) in the Tamworth Group (Crook, 1961*a*) all indicate that calcite was a stable phase in the depositional environment. The Parry Group, Drik-Drik Formation, Yarrimie Formation and limestone-bearing parts of the Silver Gully Formation then, were apparently deposited in water less than 15,000 ft deep (Sverdrup *et al.*, 1942).

Biochemical silica is prominent in the Yarrimie Formation, in the form of siliceous argillites and radiolarian and spicular cherts (Crook, 1960*a*), which are similar to the cherts of the Monterey Formation of California. Pelagic sedimentation is indicated (Campbell, 1954, p. D17), and a relative absence of terrigenous detritus. Deep water is not a necessary corollary (Riedel, 1959). However, a low energy environment with negligible turbulence appears to be necessary for the accumulation of biogenic siliceous rocks (Bramlette, 1946). This suggests that much of the Yarrimie Formation accumulated in quiet water, more or less cut off from sources of terrigenous detritus.

The lower part of the Drik-Drik Formation—breccia, arenite and silty shale—is bright red to purple-red. This is presumably due to anhydrous ferric oxide pigment which was developed in the detritus under terrestrial or littoral conditions. The preservation of the colour indicates a maintenance of oxidizing conditions within the sediment during and after burial. This suggests terrestrial deposition, or rapid deposition in a marine environment.

The Hawk's Nest Beds (Crook, 1961*a*) accumulated in a euxinic environment. The rocks are dark, the shales being black and pyritic. Plant fragments, carbonized and simulating graptolites, are common.

Fossils

Coralline biolithites (i.e. biohermal limestones) occur in both the Yarrimie and the Drik-Drik Formations. Hill (1956, p. F255) considers that Palaeozoic compound rugose corals lived in environments of similar depth and possibly similar temperature to those in which modern colonial corals occur. Rather shallow, probably well aerated, warm water is therefore suggested for the deposition of the Moore Creek, Crawney, Timor, and Nemingha Limestones. The Loomberah Limestone, being a biorudite with abundant terrigenous clasts, probably reflects a different environment.

In the top few hundred feet of the Parry Group, a typical shallow water benthonic fauna with abundant brachiopods and bryozoans is common (Fig. 3). Similar faunas occur at Babbinboon (Campbell, 1957) and Merlewood (Carey, 1937). Benthonic forms also occur sporadically in the red shales of the Drik-Drik Formation. Fossils in all of these assemblages are not worn and can therefore be used as environmental indicators.

At three points: between Members 6 and 7 of the Pyramid Hill Arenite on Wiles Gully; immediately above the Turi Graywacke on Boiling Down Creek; and above the Gowrie Sandstone on Spring Creek; shelly benthos has been encountered. In all occurrences the fossils are either worn or occur in slumped or graded beds, and thus appear to be re-sedimented. These fossils are of little value for environmental reconstructions.

Trails, especially *Chondrites*, occur in the mudstones and siltstones of the Parry Group (Crook, 1961*b*). A soft-bodied benthos apparently was able to live under the conditions of deposition of parts of the sequence. Much of the sequence, however, is barren except for pelagic forms, chiefly *Radiolaria*, suggesting water too deep for benthonic forms to survive.

A death-assemblage flora occurs in the Goonoo Goonoo Mudstone between the Kiah Limestone and Baldwin Formation. It consists mainly of *Leptophloeum* and related forms, and is locally quite abundant (Crook, 1961*b*). While not significant from the standpoint of depositional environment, it probably records significant events in the source area.

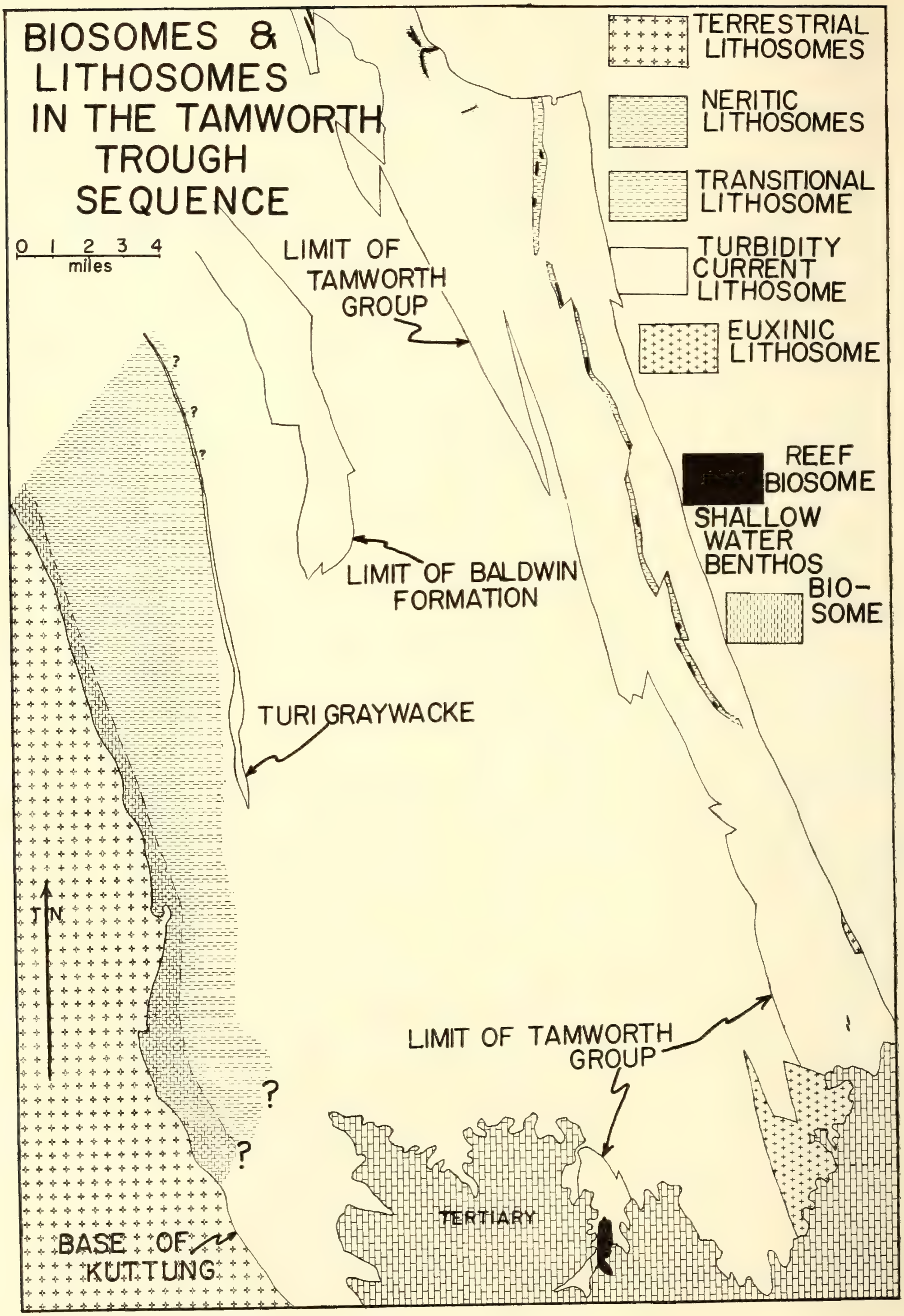


FIG. 3

Biosomes and lithosomes in the Tamworth Trough sequence. Outcrop limits of Turi Graywacke, Baldwin Fm., Tamworth Group, Kuttung and Tertiary are shown

TABLE 2

Stratigraphic Distribution of Sedimentary Structures

	Deep Water Structures								Ambiguous Structures										Shallow Water Structures		
Stratigraphic Unit*	Graded Bedding	Extensive Sedimentation Units	Convolute Bedding	Load-cast Structures	Flute Casts	Flow Casts	Slump Structures	Pull-aparts	Micro-X-strat.	Ripple Marks	Worm Tracks	Ripple Lamination	Mud Balls	Discontinuous Curved Lamination	Shale Pebbles	Shale Breccia	Current Lineation	Plant Remains	X-Stratification	Lenticular Sedimentation Units	Scour and Fill
Clp_2																		×			
Clp_4														×					×		
Clbs																	×			×	
Clg to Clp_{4a} ..		f											×					×			
Clp_5		f					×		×	×		f			×				×	×	
Clp_7	r						×								×				×	×	
Clgs															×	×			×	×	×
Clg to Clp_8 ..	×	f					×		×		×			×	×	×		×			
Clp_R														×							
Clp_U									r												
Clp_V														×							
Clp_8	×		×				×							×	×	×		×			
Clp_9														×	×	×					
Clp_{10}														×							
Clt	×	×														×					
Clbg																×					
Clw	×	×					×		×					×	×	×				r	r
Cls	×	×		×																	
Clh															×						
Clg to Dub ..	×		×		×	×	×		×	×	×	×			×		r	×	r	f	
Duk		×																			
Dub	×	×		×	×		×		×	×	×				×						
Dmy	×	×	×	×	×	×	×	×	×	×	×				×	×		×	r	r	
Dms ..	×	×													×						
Dlw	×	×		×																	
Dld	×	×																			
Dlp	×	×																			
Dh	×	×					×		×	×					×	×		×			

r=rare ; f=finegrained units

* For list of stratigraphic units corresponding to symbols, see Table 1.

Summary of Depositional Environments

Synthesis of the data given above leads to an inferred depositional environment for each formation as shown in Table 3. These inferences follow directly except in the case of the Yarrimie Formation. Here coralline biolithites (biohermal limestones) indicative of shallow water coexist with cherts and graded bedded graywackes indicative of turbidity current action which is usually confined to deep water.

For the greater part of its area of outcrop between Tamworth and Nundle, the Yarrimie Formation presents a mixed pelagic and turbidity current aspect, and must therefore have accumulated in water sufficiently deep to prevent traction current re-working. The abundance of pelagic sediment suggests a general paucity of terrigenous detritus entering the trough over much of its extent. Only locally are thick graywacke units developed, and here biolithite limestones are absent.

North of Tamworth and south-west of Nundle, biolithite limestones become prominent and the proportion of turbidites in the sequence appears much reduced. In these areas the Yarrimie Formation appears to have accumulated in

TABLE 3

Depositional Environments of the Various Units

Unit	Environment	Evidence
Goonoo Goonoo Mudstone	Marine throughout; shallow water in upper parts, deepening down sequence, and passing into deep-water at some horizon between Members 7 and 8 of Pyramid Hill Arenite. Thereafter deep water to base of unit	Sedimentary structures and fossils indicate change of environment. Importance of turbidite structures in much of succession.. Existence of pebbly mudstones
Baldwin Formation	Deep water marine	Sedimentary structures
Yarrimie Formation	Marine throughout; probably deep water in the region from Tamworth to Nundle, shallower water, with bioherms and pelagic sedimentation north of Tamworth and southwest of Nundle	Fossils, sedimentary structures, chemistry of sediments, distribution of rock types
Silver Gully Formation	Marine; probably deep water	Fossils, limestone, sedimentary structures
Wogarda Argillite	Marine, deep water	Sedimentary structures
Drik-Drik Formation	Upper part deep water marine shallowing rapidly down sequence, with shallow water marine and possibly terrestrial deposits in the lower (red) parts	Sedimentary structures suggest changing environment. Chemical features of sediments, fossils, grain shape important for lower part of unit
Pipeclay Creek Formation	Probably deep water marine	Sedimentary structures
Hawk's Nest Beds	Deep water marine, poorly aerated	Sedimentary structures, chemistry

shallow water, despite the absence of supporting evidence from the argillites. If the water were shallow, traction current activity must have been negligible, for there is no disturbance of lamination in the argillites. It is not clear why these conditions should have prevailed and the available evidence does not permit solution of the problem.

The Yarrimie Formation, then, apparently accumulated in water of variable depth. There appears to be no reason to assume anything other than deep water in the region between Tamworth and Nundle. North and south of this region the water must have been shallow enough to allow the growth of colonial corals.

Lithosomes and Biosomes

The lithosome-biosome concept of Sloss *et al.* (Weller, 1958, pp. 624–627) is of value in understanding the Tamworth Trough sequence. Lithosomes and biosomes are, in Sloss's usage, the *rock records* of, respectively, uniform depositional and biological environments. They are related to lithotopes and biotopes which, according to Sloss, are *areas* of uniform depositional and biological environments. Although a lithosome is a lithostratigraphic unit, and a biosome is a biostratigraphic unit, there are no necessary relationships between these units and conventional stratigraphic units (Australian Code, 1959).

Lithosomes: Figure 3 shows the lithosomes and biosomes found in the sequence under discussion. The dominance of rocks recording a turbidity-current-dominated environment is immediately apparent. Except on the western edge of the area, shallow water (neritic) lithosomes are of local significance only.

A mixed turbidity current-neritic lithosome occupies the interval between the neritic and turbidity current lithosomes in the west of the area. In this lithosome sedimentary structures suggest an intermingling of sediments deposited by traction currents and others deposited by turbidity currents. The limits of this transitional lithosome are vague, particularly in areas with few arenites, and it is mappable only in a generalized fashion. The sequence from the top of Member 5 to the base of Member 7 of the Pyramid Hill Arenite lies within this lithosome.

The transitional lithosome records a gradual shallowing of the water in the trough with consequent increase in traction current activity. Its top marks the appearance of water sufficiently shallow for the obliteration of all traces of turbidity current activity by reworking.

In the north-west the transitional lithosome may transgress one of the stratigraphic units, the Turi Graywacke Member. This unit is certainly within the turbidity current lithosome at its southern end on Spring Creek, but further

north its designation is not clear. This apparent transgression, if valid, suggests that the trough may have shallowed north-westwards along its axis, as well as south-westwards perpendicular to its axis. The widespread development of coralline biolithites in the Tamworth Group at Attunga north of the map area supports this suggestion of axial shallowing.

North-west of the area shown in Fig. 3, on the western margin of the trough near Keepit Dam, traction current deposits form much of the sequence above the Baldwin Formation, and these apparently extend eastwards towards Klori (Chappell, 1961, p. 69, Table 1). This again suggests axial shallowing.

The validity of the hypothesis of axial shallowing cannot be properly assessed until the area between Keepit-Klori and that covered by Fig. 3 is mapped. Nor will it be possible to rationalize the nomenclatural differences that exist between the two separated areas (compare Chappell, 1961, and Voisey, 1958, with Crook, 1961*a* and 1961*b*).

The hypothesis of axial shallowing is important, considering the different approaches that have been taken to stratigraphic subdivision. Crook (1961*b*) used mappability and petrographic differences as primary criteria in erecting the Parry Group, his reference to " the lithogenetic unity of the sequence " (1961*b*, p. 195) being from the viewpoint of provenance rather than of depositional environment. Chappell (1961, p. 69) has used change in depositional environment as a primary criterion for recognizing the top of the Mandowa Mudstone, hence this boundary is both a stratigraphic and a lithosomal boundary.

If axial shallowing occurs, the lithosomal boundaries might cross the boundaries of Crook's stratigraphic units as these were traced northwards. It is thus conceivable that, in some areas, both Crook's and Chappell's nomenclature could be applicable, and the units of Chappell's nomenclature would intersect those of Crook's.

This possibility does not necessitate the complete suppression of one or other nomenclature, however, as there may be areas (and the author considers that within Map 3 to be one), in which the lithosomal boundaries are too diffuse to be mappable in more than a generalized manner, and hence Chappell's nomenclature is not applicable.

Biosomes: Figure 3 shows two recognizable biosomes, one characterized by shelly benthos, particularly brachiopods, and the other by coral reefs. Both are shallow water biosomes.

The shelly benthos biosome is included within the neritic lithosome, and its restriction to the western and stratigraphically higher parts of this lithosome suggest that it records water shallower than that occurring when the lithosome was initiated.

The occurrence of the reef biosome within the turbidity current lithosome in parts of the Tamworth Group reflects the conflict in data already referred to. Elsewhere in the Tamworth Group, in the lower part of the Drik-Drik Formation or its equivalents, the reef biosome lies within a shallow water lithosome.

Provenance Directions

The value of sedimentary structures in determining provenance directions has been ably demonstrated by Crowell (1955) and other workers. The following structures have been used in this study: ripple marks, cross-stratification, plant fragment lineation, slump structures, convolute bedding, flute casts, flow casts, and current lineation.

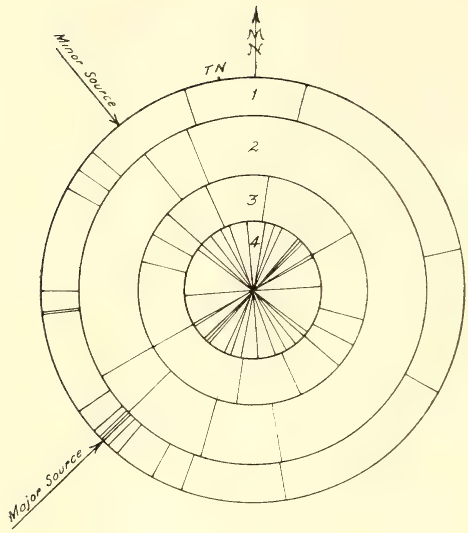
Unfortunately, suitable occurrences, particularly of sole markings, are not common. This led to the use of poorly oriented structures such as plant fragment lineation, and also cross-stratification, which may be quite variable in direction (Crowell, 1955).

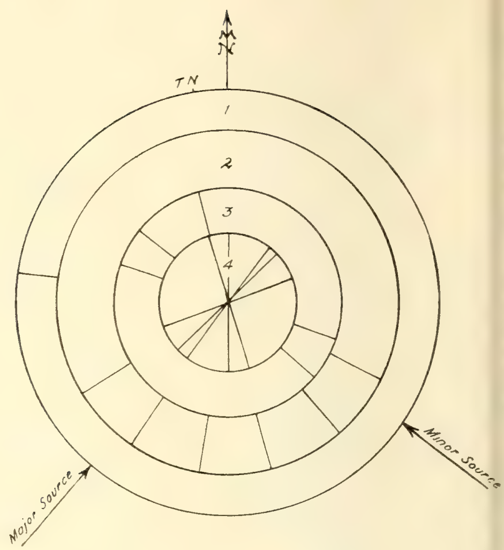
Data obtained (Appendix II) are plotted on Figs. 4–7. In the Tamworth Group data are available only from the Yarrimie Formation and the Hawk's Nest Beds.

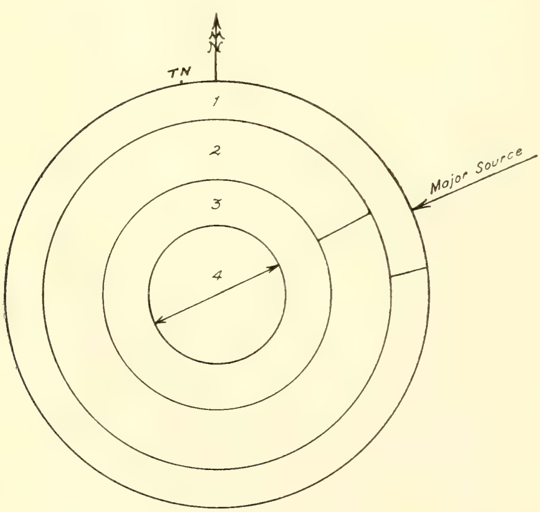
There is a consistency throughout the sequence suggesting that the overall shape of the trough remained fairly constant throughout Devonian and Early Carboniferous time. The main provenance direction in all units except the Baldwin Formation is from 210° to 245°. The meagre data available from the Baldwin Formation hint at an easterly derivation. A minor provenance direction from 320° to 350°, roughly perpendicular to the major direction, and an occasional south-easterly component, are also present.

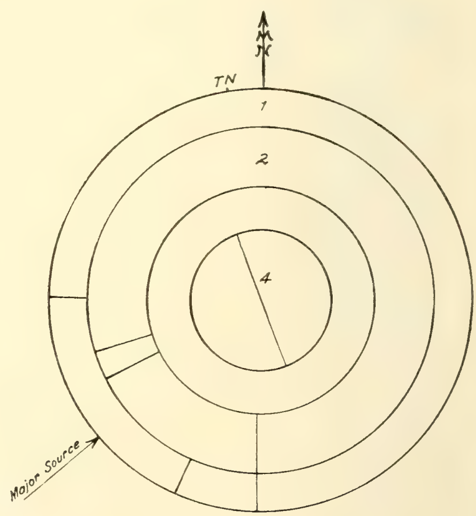
Isopachs on the Goonoo Goonoo Mudstone (Crook, 1961*b*) suggest that the Tamworth Trough was elongated along a 340°–160° axis, with a shoreline on its south-western side. The main provenance direction supports this, but it may be necessary to postulate a north-east shoreline in the Late Devonian, for the Baldwin Formation.

The minor provenance direction suggests transport of sediment from the north-west along the axis of the trough. This supports the









Figs. 4–7

Fig. 4—Source directions—Goonoo Goonoo Mudstone and Wombramurra Formation
Fig. 5—Source directions—Baldwin Formation
Fig. 6—Source directions—Yarrimie Formation
Fig. 7—Source directions—Hawk's Nest Beds

postulate of axial shallowing to the north-west. Such a mode of filling has been demonstrated in Alpine basins (Kuenen, 1957) and in the Polish Carpathians (Dzulynski *et al.*, 1959).

Throughout much of its history, the Tamworth Trough appears to have contained deep water, shallowing to the west, and possibly also to the north. Much of the sediment was contributed from the western side, and a smaller amount entered from the north-west, along the axis of the trough. The axial contribution may, however, have its ultimate source marginal to the trough, being contributed by currents which travelled laterally at first, and then turned and flowed south-eastwards along the axis of the trough.

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Appendix I

Statistical parameters and locations of measured mudstone successions

(Parameters calculated from formulae analogous to those of Folk and Ward, 1957. Grid References refer to maps in Crook, 1961*a* and 1961*b*)

Locality 1: Below Clp_6, Jacob and Joseph Creek, 062120 Nundle.
Mean $CF = 2 \cdot 73$; $\sigma = 0 \cdot 775$.

Locality 2: Above Clp_7, Jacob and Joseph Creek, 064117 Nundle.
Mean $CF = 2 \cdot 11$; $\sigma = 0 \cdot 671$.

Locality 3: Below Clbg, tributary of Upper Goonoo Goonoo Creek, 129086 Nundle.
Mean $CF = 0 \cdot 75$; $\sigma = 0 \cdot 323$.

Locality 4: Below Clp_8, Merri Creek, 092107 Nundle.
Mean $CF = 0 \cdot 21$; $\sigma = 0 \cdot 100$.

Locality 5: In Clp_8, Stockyard Gully Creek, 099119·5 Nundle.
Mean $CF = 0 \cdot 31$; $\sigma = 0 \cdot 089$.

Locality 6: Mudstone within Clw, Oakey Creek, 211044 Nundle.
Mean $CF = 1 \cdot 86$; $\sigma = 0 \cdot 630$.

Locality 7: Below Clt, Swamp Creek, 072220 Goonoo Goonoo.
Mean $CF = 1 \cdot 29$; $\sigma = 0 \cdot 605$.

APPENDIX II

Current-directional Data

Formation	Type	Sequence: Dips To °	Sequence: At °	Crests or Lineation: Rakes	Crests or Lineation: At °	Sense from	X-strat–App. dip: To °	X-strat–App. dip: At °	X-strat–App. dip: Face Dips to °	X-strat–App. dip: At °	Component from	Source °
Clg below Clp_4	Wood	272	24	S	84							266; 86
,, ,, ,,	Plants	280	23	horiz.								10; 190
,, ,, Clp_5	Slump	200	37	S	40	250°						240
,, ,, Clp_6	Plants	250	15	horiz.								340; 160
,, above Clp_7	X-strat	150	6				130	15	true dip			310
,, below Clp_Q	Slump	75	30	SE	30	255°						225
,, ,, Clgs	Flute cast	260	10	horiz.		sth						170
,, above Clp_U	X-strat	220	60			220°						220
,, below Clp_8	Plants	240	10	NNW	23							307; 127
,, above Clp_9	Wood	265	11	horiz.								355; 175
,, below Clp_9	X-strat	276	14			225°						225
,, ,, ,,	,,	,,	,,			180°						180
,, ,, ,,	,,	265	21				186	15	96	82		14
							horiz.		190	90		
,, above Clp_{10}	,,	275	15				300	22	true dip			118
,, below Clp_{10}	Plants	271	24	SW	17							198; 18
,, ,, ,,	Ripple	204	22	horiz.								204; 24
,, ,, ,,	,,	204	22	SW	80	W						304
,, ,, Clp_Z	X-strat	235	55			235°						235
,, ,, ,,	Slump	245	68	SW	90	S or N						335; 155
,, ,, ,,	,,	246	68	SW	90	N						336
,, ,, ,,	Flow cast	230	62	S	68	W						298
,, above Clbg	Slump	320	27	N	38							104; 284
,, ,, Clt	Convol. bed	240	41	horiz.								240; 60
,, ,, ,,	Ripple		low	310°								40; 220
,, ,, ,,	Current lineation	246	15	NW	25							311; 131
,, ,, ,,	X-strat					SW						SW
,, below Clt	,,	177	26								W, near 270°	W
,, ,, Clgc	Ripple		low	328°								238; 58
,, ,, ,,	,,	245	15	N	10							240; 60
,, within Clw	X-strat	51	60								SW	SW
,, ,, ,,	,,	50	48				N	47	264	72		228
							str.	315	horiz.			
,, above Cls	Ripple		low	330°								60; 240
,, low	,,	45	36	horiz.								45; 225
,, ,,	X-strat					*ca.* 200°						200
,, ,,	,,	260	53				S	26	150	53		264
							horiz.		85	70		
Clp_2	Wood		low			295–320°						310; 130
Clp_{3a}	,,		,,			320°						320; 140
Clp_4	X-strat	230	18				S	5	93	61		78
							S	17	126	51		

APPENDIX II—*continued*

Current-directional Data

Formation	Type	Sequence: Dips To °	Sequence: At °	Crests or Lineation: Rakes	Crests or Lineation: At °	Sense from	X-strat–App. dip: To °	X-strat–App. dip: At °	X-strat–App. dip: Face Dips to °	X-strat–App. dip: At °	Component from	Source °
Clp_{4a}	Wood	horiz.				42						42; 222
Clp_7	X-strat										170°	170
,,	,,	250	15								340°	340
Clp_5	Plants	259	20	NW	20							329; 149
,,	Ripple	230	17	W	34	SE						196
Clp_8	Plants	150	7			20						20; 200
Clp_9 ?	Convol. bed	horiz.		233	320							320
,,	Wood	horiz.		310								310; 130
,,	Flute casts	horiz.		187								187; 7
Clgs	X-strat	160	13				100	20				263
							15	5				
,,	,,	125	10				111	8				298
							74	6				
Clw	,,	40	56				E	38	155	17		28
							NW	73	319	44		
Dub	,,	66	56				N	7	280	31		4°
							SE	58	165	58		
,,	Flute casts	250	78	S	84	70						62
,,	Ripple	245	38	horiz.								245; 65
Dmy	X-strat	220	14				145	25	surfaces perp. bedding			
							50	7				278
,,	Ripple			230		SE						140
,,	Convol.			220								310; 130
,,	Flute casts	248	54	SW	8							166; 346
,,	Ripple	horiz.		160								250; 70
,,	,,	235	80	NW	17							218; 38
,,	Slump	245	70	S	45							290; 110
,,	,,	148	48	SE	90	SW						238
,,	Convol.	125	58	NE	65	SW						190
,,	,,	145	65	W	27	E						118
,,	,,	125	67	NE	90	W						215
,,	Ripple	130	62	E	50							360; 180
,,	,,	130	62	SW	84							226; 46
,,	,,	130	62	E	44							344; 164
Dh	Slump	282	80								242°	242
,,	X-strat	252	70				N	34	85	25		228°
							W	25	187	57		
,,	,,										W	W
,,	Ripple	280	8	N	17	S						253
,,	Plants	265	5	NW	15–20							339; 159
,,	X-strat	264	68								S	S
,,	Slump	E	85								S	S

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Petrology in Relation to Road Materials
Part II : The Selection of Rock for Road-making in Australia, with special reference to New South Wales

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Abstract—Three factors affecting the selection of rock for use in road-making are discussed, namely distribution, workability and quality. The conclusions are considered to apply to most of Australia.

The laboratory test results for over 3,000 specimens have been examined in the Dept. of Main Roads, N.S.W., records, and from typical examples the average test results for 17 types of aggregate have been assessed to decide what types of rock most consistently supply aggregate conforming substantially with specifications. The answer given is 83% compliance for Dolerite, 76% compliance for Basalt and Quartzite, 75% for Microdiorite and 70% for Microgranite, Slag and Limestone. However, Limestone is rated in this paper as the best for use as artificial road-gravel.

A modification of the existing approach to specifications is discussed.

Introduction

The suitability of a rock deposit for use in road-building whether it is intended to be used in the base course or surface course is decided by (i) its position relative to the proposed work, (ii) the workability of the deposit, and (iii) the quality of the rock for the specific purpose.

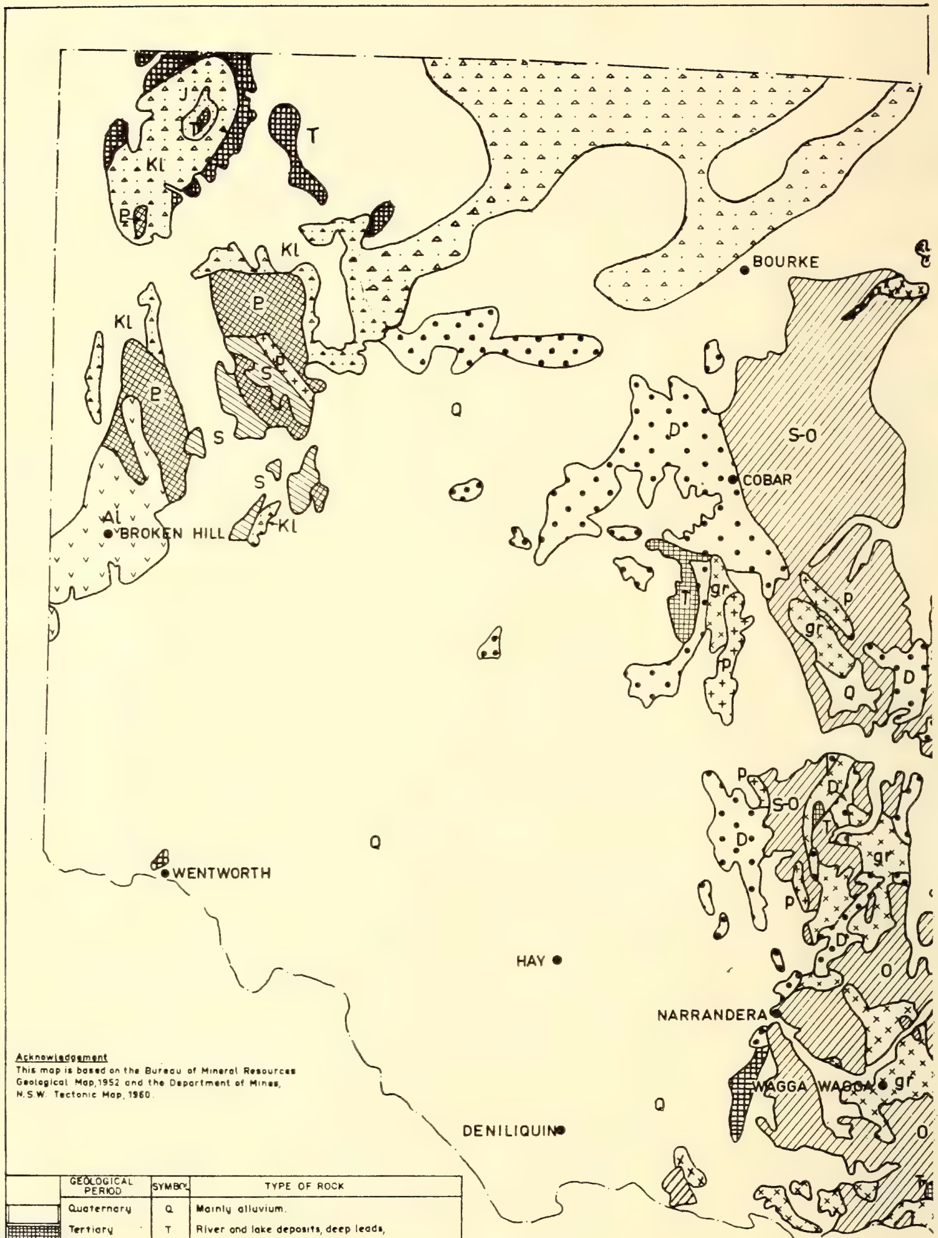
It is suggested by the present author that in attempting such an assessment the aim should be to select rock that will give the best service on the road measured in pounds (currency) per cubic yard of pavement with such costs determined not merely on initial cost but rather on the cost spread over a ten-year period including maintenance, the *cheapest* available material being selected on this basis.

Road-building authorities charged with the administration of public funds tend to be over-cautious and accept arbitrary specifications in many cases imported from overseas that are unsuited to Australian conditions in the opinion of the present author. It is true, of course, that the various State Road Authorities are tackling this problem and the Universities show some interest, but at this time the Australian Specifications are frequently just echoes of British and American specifications, sometimes out of context, e.g. the Los Angeles test method given in the Australian Standard A77/1957. Some allowance must of course be made for these shortcomings since a start must be made somewhere, and it is only in the last few years that a university has recognized the need for a Chair in Highway Engineering, that an Australian Road Research Board has been established, and an Institute of Highway Research started. Graduates of many different kinds are needed to tackle the problems existing, and all of them should have a practical knowledge of road-building in order to make intelligent contributions, whether they be engineering chemists, engineering geologists or highway engineers.

Factors in Selection Relative to the Distribution or Mode of Occurrence of Different Rock Types

(1) *Aggregate.* It is pertinent to consider at this stage what types of rock find the most frequent use and why. In New South Wales the distribution of the principal rock types used for aggregate is set out on the accompanying map (Fig. 1). The most common rock type (quarried basalt) is not the one covering the greatest area. Quartzite, limestone and micro-diorite are the next most commonly used types in that order (Minty, 1960).

Basalt is probably more often selected as aggregate on account of its historical use than for any other reason ; but since most basalts in New South Wales are Tertiary residuals, they are usually perched on top of high ground in convenient positions for the establishment of quarries. Geologically older rocks would frequently require the removal of overburden in excessive proportions.



	GEOLOGICAL PERIOD	SYMBOL	TYPE OF ROCK
	Quaternary	Q	Mainly alluvium.
	Tertiary	T	River and lake deposits, deep leads, diatomaceous earth, etc.
	Cretaceous	Ku Kl	Surface outcrops are mainly sandstone
	Jurassic	J	Porous sandstone in many areas, ***shale etc***.
	Triassic	℞	Shales and interbedded sandstone.
	Permian	P	Mainly sandstone and conglomerate with interbedded shales and coal.
	Carboniferous	C	Tuffs with interbedded lava and conglomerate
	Devonian	D	Much quartzite and sandstone with interbedded conglomerate and shale, etc.
	Silurian	S	Mildly metamorphosed fine grained sedimentary rocks interbedded with limestone, tuff and lava.
	Ordovician	O S-O	Mainly slate and quartzite with some limestone, tuff and agglomerate.
	Proterozoic	P̶	Metamorphosed sediments of the Tarrowangee series.

	GEOLOGICAL PERIOD	SYMBOL	TYPE OF ROCK
	Archaeozoic	Al	Willyama complex gneisses, granite gneiss etc.
	—	gr	Granite ***and Granodiorite***.
	—	p	Porphyry
	—	Ta	Andesite. (Tertiary) ***Some Permian Pa***.
	—	Tb	Basalt (Tertiary) ***Some Jurassic Jb***.
	—	sp	Serpentine.

FIG. 1

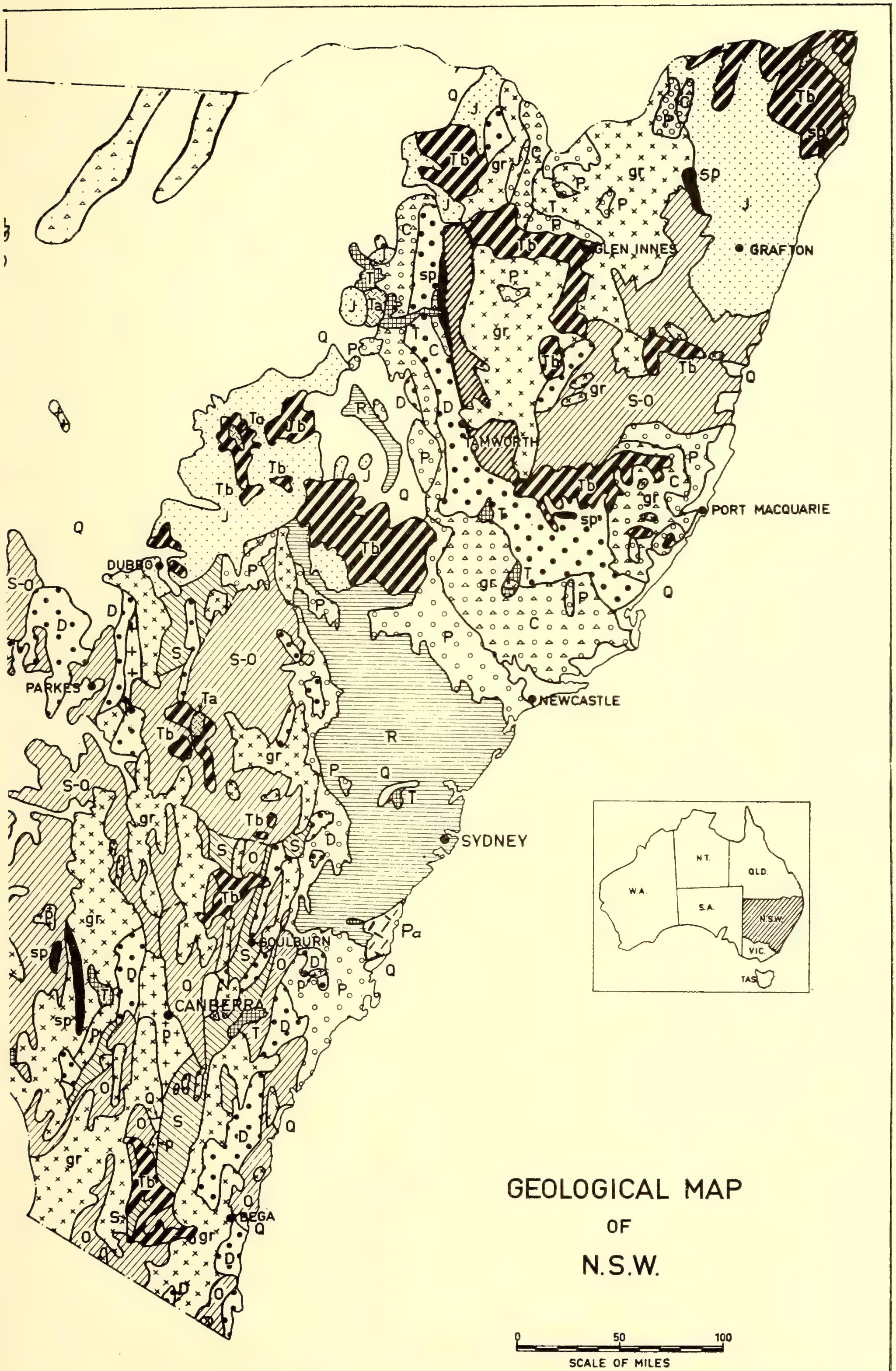

GLEN INNES
GRAFTON
TAMWORTH
PORT MACQUARIE
DUBBO
PARKES
NEWCASTLE
SYDNEY
GOULBURN
CANBERRA
BEGA
N.T.
QLD.
W.A.
S.A.
N.S.W.
VIC.
TAS.
GEOLOGICAL MAP
OF
N.S.W.
0
50
100
SCALE OF MILES

FIG. 1

Similarly, quartzite enjoys popularity as aggregate on account of the well exposed outcrops in many parts of the State.

The selection of limestone as aggregate is not so frequently due to good exposure. In fact some limestone quarries are in difficult positions subject to the ponding of water, as most limestone in New South Wales is interbedded with other Ordovician, Silurian or Devonian rocks. Difficulty occurs when the dip is steep in country of low relief.

River gravel is the most common type of aggregate used in New South Wales but is usually of mixed rock types, hence its exclusion from the foregoing discussion.

(2) *Road Gravel.* By " road-gravel " the engineer means a mixture of gravel, sand, silt and clay in such proportions that the smaller sizes fill the voids between the larger particles, resulting in a dense pavement when compacted.

With the exception of limestone, the kinds of rock finding use as " aggregate " seldom crush to give a well graded mixture of high compressive strength such as that required for " road-gravel ". On this account and because of the immense quantities of road-gravel required to build an average road, a great variety of naturally-occurring soils find use for this purpose. However, resources of the latter kind are dwindling and other materials are being used. Cement and lime stabilization have extended the range of soils that can be used, but fine-grained soils require the addition of relatively large amounts of cement or lime and therefore do not compete with locally crushed rock for road-making if the winning and crushing costs for local rock are reasonable. This is especially true in the central west of New South Wales where, as shown on the map, rock outcrops are quite extensive.

It is possible to see the broad trends in distribution of the various types of road-gravel by examination of the materials map (Fig. 1). These areas may be described briefly as follows :

Alluvium—For the most part the areas so described are a wasteland from an engineering viewpoint, containing as they do much " black " clay soil. However, in the Riverina there is a remarkable system of old streams (David, 1932 ; Langford Smith, 1960 ; Butler, 1956) no longer flowing but containing enormous resources of sandy loam suitable for road-building. Some useful deposits of this kind have also been found between Warren and Collie, Warren and Nyngan, out from Nyngan and Forbes, and near Coonamble. In most cases where they have been rivers fine wind-blown sandhills derived from these sediments are found nearby.

In " Soils of the Macquarie Region " the C.S.I.R.O. (1955) has described the soils of the plain through which the Macquarie River wanders. Another soil survey (Water Conservation and Irrigation Commission) supplies some useful information near Nyngan.

Shale—While true shales only outcrop extensively in the Wianamatta basin, they are interbedded with other sedimentary types in the basins of Devonian, Carboniferous, Permian and Jurassic age. Their use for roads depends firstly on the outcrop being reasonably free of overburden. Sometimes they are exposed in the saddles of Devonian hills or on the escarpment of Devonian, Carboniferous and Permian strata. Thus, on the map the areas shown as mainly sandstone and mainly quartzite will be found to contain shale which may be of use in road works.

Sandstone—Although Telford base courses are a thing of the past, sandstone crushed to about 4 in. size has been used in road construction in recent years near Gosford. (It can be handled just as road-gravel and is reduced to a Macadam-like grading simply by rolling.) Sandstones sometimes are found broken down to a good road-gravel through soil forming processes, but around Sydney the sandstone is too even grained to produce well graded soils. Somewhat gritty sandstone soils and partly decomposed sandstone have been used along the Hume Highway in Wingecaribee Shire, near Mt. Victoria on the Great Western and north of Dubbo on the Newell Highway. These beds all outcrop near the edge of sandstone areas and are basal beds once fed by vigorous streams. Although there is some conglomerate rock in these areas many of the pebbly gravels used for road-gravel such as those near Robertson and Mittagong are alluvium eroded from the basal beds and redistributed by river action, later covered by basalt flows and only now exposed in part by erosion (Plate I).

Quartzite—Quartzite is widely distributed, particularly in the Upper Devonian, but seldom provides road-gravel. Such deposits however are not unknown in areas where the topography is conducive to the formation of deep colluvium such as the area between Rylstone and Cudgegong.

Conglomerate — Suitably decomposed conglomerate of various geological ages finds use

as road-gravel in widely scattered areas of the State.

Limestone—When used, limestone is generally crushed but sometimes gives rise to Kunkar, which finds use as road-gravel near Gunningbland, Wentworth and between Menindee and Broken Hill. Crushers at Marulan, Ilford, Molong, Forbes, Galong and elsewhere have supplied good artificial road-gravel.

Slaty Rocks—A variety of rock types is embraced by this description. By slaty is meant any metamorphosed sedimentary rock which has closely spaced cleavage, joints and bedding arranged in different planes such that angular fragments are derived on disturbance of the rock. Slaty rocks have been much used as road-gravel in New South Wales and their use will certainly increase as they are not only widespread but supply deep deposits, of both colluvium and rock.

Granites and Porphyries—Amongst this class only granite soil or regolith is normally used for road-gravel and not the rock, the porphyries rarely find use because they tend to form erratic deposits.

Tuffs—Are not much used, although tuffaceous slates are used.

Basalts and other basic igneous rocks are crushed and used as road-gravel but do not form deposits of good natural road-gravel. In fact basalt more often spoils than provides good gravel. Such spoiling is of course due to the formation of rich soils (usually red).

Dolerites and Microdiorites—Decomposed rocks of these types have been used in rare cases, but could not be regarded as good road-gravels.

Pebbly Alluvium—Whilst much used for road-gravel, when suitably graded, this class of material is difficult to record on a generalized map.

Laterite—This material also supplies extensive road-gravel deposits, notably along the coast, but being superficial has not been shown on the map.

Factors in Selection Relative to the Workability of Rock

(1) *For Aggregate.* The ease of winning and the ease of crushing are the principal factors. River gravels are won simply by digging or dredging. However, winning generally means drilling, blasting, loading and transport to the crusher. Hard rocks are the more costly to drill except that very open joints filled with soft decomposition products can provide a hazard in rock of any hardness. Blasting is generally assisted by incipient joints but is hampered by open joints. Loading and transport are primarily assisted by the quarry face being above the crusher, and secondarily by the size of the blocks dislodged by blasting being of optimum size. The latter is governed by the closeness and pattern of jointing in the rock as well as the pattern and type of charge.

So it is that the difficulty of winning the more commonly used rocks is on the average in the order micrognanite, microdiorite, granite, quartzite, dolerite, basalt and limestone, assuming that all are situated in similar topographic locations.

However, there are some cases (Plate I) in which the jointing is so well developed that the rock can be dislodged from the face with a power shovel, thus saving drilling and blasting and also speeding up loading. This is a similar category to river gravel and has applied to weathered conglomerate, slaty limestone and extremely jointed basalt in certain New South Wales quarries. It is to be expected that some quartzites and cherty slates would fall into this category.

The difficulty of crushing (W) is probably proportional to the product of the size of blocks (S) won from the deposit and the load (F) required to produce 10% of fines (D.S.I.R., 1959) from rock of the type being crushed, divided by the average size (a) of aggregate produced. That is,

$$W = c/a(FS)$$

where c is a constant.

(2) *For Road-Gravel.* The natural road-gravels are of course the cheapest to win and require little or no crushing. In the rocks used as artificial road-gravel there is a gradation from the aggregates discussed above into types only suitable for use as road-gravel.

Jointing, bedding, shear planes and grain size all influence workability. The ideal materials are those which are sufficiently fissile to be quarried by machine (ripper or shovel) and such that the blocks are not above 9 in. on the largest dimension of the maximum sized pieces, with an average of 3 in. or less (Plates II and III). Usually such material can be broken down to an artificial road-gravel by special rollers (grid or cleated).

The slaty rocks frequently follow this pattern. Shales, sandstones and conglomerates are more difficult, shales and sandstones generally on

TABLE I

Typical Test Results for Different Rock Types Contrasted with Specifications

Test	Los Angeles (% Loss by Impact and Abrasion)	Plate Stripping Test (% which fails to adhere to bitumen)	Flakiness Index (% of flaky pieces)	Sodium Sulphate Soundness (% breakdown)	Soundness by Testing Soaked Aggregate with Pliers (% crumbled)	D.M.R. N.S.W. Lab. Coefficient of Friction under extreme conditions	English D.S.I.R. Polished Stone Coefficient
Typical Specification Limits	A = Max. of 20 for dense traffic conditions B = Max. of 27 C = Max. of 35 for light traffic or use in concrete	Maximum 20%	Maximum 30%	Maximum 10%	No Specification in use but 5% suggested by the author		No Aust. Spec. yet adopted but Giles (D.S.I.R. Eng.) sets 0·4 as a Min. and 0·6 desirable
Typical Test Results for Various Rock Types							
Granite	32 (range 16–45)	100% unless pre-coated with tar	14%	—	2%		0·56
Microgranite	18 (range 16–22)	92% ,, ,,	16%	8%	—		0·51
Rhyolite	16 (range 15–17)	100% ,, ,,	23%	—	—		
Microdiorite	15 (range 11–15)	75% ,, ,,	12%	less than 2%	—		0·51
Dolerite	21 (range 13–25)	48% ,, ,,	23%	less than 2%	—	0·46 (0·38 on field evidence)	
Basalt	15 (range 9–21)	68%* ,, ,,	25%	2%	—	0·41	0·56
Quartz	36 (range 24–44)	100% ,, ,,	—	—	—		
Slate	21 (range 13–25)	73%* ,, ,,	12%	1%	—	0·33	
Quartzite	23 (range 12–40)	85% ,, ,,	22%	—	4%	0·47	0·57
Hornfels	17 (range 14–22)	93% ,, ,,	32%	—	1%		0·45
Greywacke	(44) (insufficient data)	—	—	—	—		
Kunkar	34 (range 31–39)	100% ,, ,,	14%	—	8%		
Limestone	23 (range 18–28)	43%* ,, ,,	25%	—	2%	0·30	0·43
Volcanic Breccia	13 (range 13–18)	93% ,, ,,	17%	—	6%	0·4 (est.)	
Schist	(23) (insufficient data)	—	31%	—	—		
Crushed river Gravel	22 (range 13–39)	100% ,, ,,	25%	some have failed	5%	0·40	
Slag	22 (range 20–40)	50%* ,, ,, *(some less than 20%)	20%	—	4%	0·30	

account of being of too large a dimension when quarried but breaking down too much during rolling, conglomerates because they tend to resist rolling unless the cobbles are of glacial origin and consist of sandstone, slaty or shaly rock.

Porphyries (microgranite, microdiorite, etc.) are sometimes jointed well enough to find use, but are not usually easy to win.

Thus fissility, not hardness, is the guide to relative workability.

Size and Uniformity of Depost

A deposit of fissile rock should only be considered if more than 10,000 cu. yds. of relatively uniform material is available, since the cost of transporting heavy plant could otherwise make the cost per ton excessive. Well tried sampling procedures are available, e.g. Dept. Main Roads Manual No. 3.

Factors in Selection Relating to Quality

It is necessary to differentiate first according to the purpose for which the rock is required, because the qualities for aggregate are quite different from the qualities required for road-gravel.

Aggregate

Whilst aggregate may be used with either bitumen or cement, it is the good all-round aggregate which must be given the highest merit, as shown in Tables 1 and 2.

It is not easy to give a simple answer on the question of aggregate quality because many of the specifications set are conflicting. Also, nature does not allow all rock types to conform equally with man-made requirements. However, the following table (Table 1) has been devised by the present author with the intention of attempting to point the way to selecting the best available aggregate in an area when establishing a new quarry.

The averages are based on an examination of the records for over 3,000 aggregate specimens, data for a selection of typical samples being set out in a thesis by the present author (Minty. 1960) and in a recent paper by West and Ross (1962).

By rating the average test results for aggregate types as set out in Table 1 for each property of interest to the engineer so that complete compliance with typical specifications scores one unit for each test and proportional compliance is similarly rated, the following sequence (Table 2) is obtained for the rock types most frequently quarried in New South Wales but omits some which are not available or are not now quarried, in New South Wales.

The author considers the present specifications are illogical. For example, a basalt having a Los Angeles loss of 27% is an inferior material even though it complies with the specification for bituminous surfacing aggregate to be used on roads carrying moderate traffic densities in New South Wales and Victoria. It is inferior because any respectable basalt belongs in the class interval 9 to 21 Los Angeles loss (Minty, 1960). Classes of rock suitable for use on a State highway carrying a certain volume of traffic could replace the blanket figure and a specification could be set for each rock type. This is not as complicated as it sounds.

TABLE 2

List of Aggregate Types in Order of Quality Assessed on the Average Test Results in Table 1

Rock Type	% *Compliance with Specifications*
Dolerite	83%
Quartzite, Basalt	76%
Microdiorite	75%
Microgranite, Slag, Limestone	70%
Granite, Slate	67%
Crushed River Gravel	64%
Volcanic Breccia	52%
Hornfels	48%
Quartz	40%
Kunkar	27%

In regard to the polishing of aggregate, the anomalous behaviour of " high class " aggregate is serious when the latter judgment is made on the Los Angeles Test result, since the 20% maximum figure for Los Angeles loss tends to exclude many rocks which are less prone to polishing than the tough fine-grained materials such as basalt, which are most prone and which in the main pass the 20% limit. Fortunately remedial measures and alternate methods of use are now available (West and Ross, 1962) as foreshadowed in Part I of this paper (Minty, 1959). It is hoped that these comments will lead to specifications being set in such a way that a better balance between conflicting limits is obtained.

For use in bituminous surface treatment a better balance between aggregate performance

and specifications could be obtained by putting the main emphasis on the susceptibility of the rock to polish so that the specification would become :

Heavy Traffic Conditions

Los Angeles Loss—Microdiorite, Dolerite, Quartzite 25% maximum on B grading or equivalent one sized counterpart.

Coefficient of Friction after 12 hours laboratory polishing (wet)—*0·45* minimum (as per West and Ross, 1962).

Stripping to be curable by the use of precoating agents such as creosote or tar, with not more than 2% of stones crumbling during the stripping test. (D.M.R. method.)

Flakiness Index—25% max.

Normal Traffic Conditions

Los Angeles Loss—(B grading or equivalent one sized)

Basalt	max. 20%	In addition to the above Classes
Slag	max. 25%	
Volcanic Breccia	max. 20%	
Limestone	max. 28%	
Granite	max. 35%	
Crushed River Gravel	max. 25%	
Slate	max. 25%	

Coefficient of Friction after 12 hours polishing—Laboratory result not to be less than 0·4.

Stripping to be curable as above, or with dehydrated tar in the bitumen. Crumbling when being removed during stripping test, max. 5%.

Flakiness Index—max. 30%.

Light Traffic Conditions

Any rock type having a Los Angeles loss of not more than 45% providing stripping can be cured with precoating or additives in the bitumen and having a flakiness index less than 35% and accelerated polishing coefficient of friction more than 0·3.

The foregoing proposals for a specification are intended to apply to aggregate for use in bituminous surface treatment work. For bituminous mixtures (sometimes described as asphaltic concrete) it is not necessary to place the emphasis on the tendency of the aggregate to polish as revealed by tests for the coefficient of friction. Aggregate as specified for either heavy or normal traffic would be satisfactory providing sharp quartz sand was included in the mix and the latter tested to give not less than 0·45 coefficient specified for heavy traffic. Actually in respect of skidding accidents legislation to require suitable fillers in tread rubber of motor tyres would be more beneficial than stringent specifications for aggregate, as shown by Table V in Part I of this paper.

In Portland cement concrete, aggregate should, in the author's opinion, comply with the Los Angeles, flakiness index and soundness requirements of either heavy or normal class aggregate for bituminous surface treatment and in addition should be reasonably free of opal, chalcedony or similar minerals likely to affect cement-alkali reaction.

Road-Gravel

The specifications for this type of material, which finds use in the base course of roads or on unsurfaced roads, usually call for a granular mixture of different sized particles such that each succeeding size just fills the void space in the preceding size and having as the terminal member of this series sufficient material finer than 0·0135 mm. diameter to act as a binder. To avoid lack of stability due to excess lubrication by the silt-clay fraction, limits are set for consistency tests whilst to ensure adequate dry cohesion a minimum dry compressive strength test figure for compacted road-gravel is laid down (Britton, 1947).

Apart from natural mixtures of gravel-sand-silt and clay finding use as road-gravel, crushed rock is now finding increasing use. When the crushing is done by a stationary crushing plant it is usually done in conjunction with the production of aggregate from fresh rock so that the product usually lacks sufficient cohesion. Taking into account rock quarried by ripping or similar techniques followed by crushing with road-plant such as cleated or grid rollers (Plate III) the type of rock usually yielding the best quality product is limestone. However, slate, volcanic breccia and some dolerites and basalts are also worth considering, providing due care is taken to blend in cohesive material to fill the voids in the sand sizes without increasing the plasticity too much.

Acknowledgement

The author wishes to thank Mr. J. A. L. Shaw, Commissioner for Main Roads, for permission to utilize the Department's records in the preparation of this paper. Thanks are also due to Mr. N. W. West, Mr. T. Ross and many of the Department's geologists for useful discussion of the subject matter, and to Mr. F. Mullin for reading the manuscript.

The opinions expressed are those of the author and do not necessarily reflect the views of the Department of Main Roads, New South Wales.

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Explanation of Plates

PLATE I

1. Pebbly alluvium of Tertiary age exposed by landslip erosion, between Mittagong and Robertson.
2. Columnar basalt, Mt. Tomah. Note the separation of the joints by weathering. Scale is denoted by the flannel flowers in the top right-hand corner.

PLATE II

1. Well developed joints in slaty rock on the South Coast.
2. Anticlinal structure in Ordovician rock west of Forbes, N.S.W. Note the power-shovel used for winning the interbedded slaty rocks (limestone and slate) and the relatively large size of fragments in the foreground.

PLATE III

1. Devonian red shaly sandstone from Speck's Gap, Jemalong Shire, won by ripping with a Michigan 'dozer. Experimental work by Jemalong Shire in 1961.
2. This shows the result of four passes of a grid roller on the large blocks in the picture above. The lane in the foreground had received eight passes of the roller.

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The Geology of the Carroll-Keepit-Rangari Area of New South Wales

A. H. Voisey and K. L. Williams*

Department of Geology, The University of New England

Abstract—The rocks comprising the Belvue Basin which lies on the same synclinal axis as the Werrie Basin in the western part of the orogenic belt of north-eastern New South Wales, have been mapped, and defined in terms of the Australian Code of Stratigraphical Nomenclature. In particular, the Tulcumba Sandstone Formation with its important Rangari Limestone Member at the base of the Carboniferous section has been recognized and described.

Introduction

This paper is the outcome of work done by K. L. Williams as part requirement for the degree of Bachelor of Science with Honours at the University of New England during 1954 under the supervision of A. H. Voisey. Mapping was carried out in the first instance on parish maps. The information was later transferred to aerial photographs and mosaics supplied by courtesy of the New South Wales Department of Lands. It has since been augmented by further field work done by the senior author and members of the Geology Department. B. A. Engel and J. W. Pickett mapped the adjacent area to the north. K. S. W. Campbell examined some of the sections and collected a number of fossils, the descriptions of which will be published elsewhere.

The area embraces the country between the Baldwin Range, west of Manilla and the southernmost extension of the Nandewar Range. It includes portions of the counties of Nandewar, Darling and Buckland and is covered by the photographic mosaics (Gunnedah sheets B and D, Attunga sheets A and C, and Boggabri sheet D).

The northernmost part of the Werrie Basin was included so that the formations might be defined in relation to those mapped so well by S. W. Carey (1934 and 1937). One of the authors (A. H. Voisey) was shown over the Werrie Basin by Carey in 1933 and was aware of the fact that he had mapped boundaries of rock formations in a manner not at variance with the principles set down by the Code of Stratigraphical Nomenclature which was later introduced (Raggatt, 1956). To give formation names now to replace the old serial ones surely should not depend upon remapping the whole of what has been regarded as the most accurately mapped Carboniferous area to which the old names of Burindi and Lower and Upper Kuttung serial names were applied. In fact, although the boundaries of rock units made originally on parish maps were checked in a number of places in the field, changes in Carey's map are few. The writers would claim to have been sufficiently well acquainted with the rocks in the field to qualify them to apply new names based upon the places where the units were originally recognized. One of the writers (A. H. Voisey) has had the mapping of the Werrie Basin revised using the units now being defined to produce one inch to the mile map sheets of the areas south of the map in this paper.

Carey's descriptions of the units have been sufficient for the writers to recognize them in the field and to map them in the adjacent areas. It was thought unnecessary to repeat descriptions of the various units since these were originally given by Carey. Moreover, use of his papers assists workers to place their units in relation to the local time-rock terms such as Burindi and Kuttung and brings new work into line with the old.

The structures lie in the Western Belt of Folds and Thrusts and are adjacent to the Border Thrusts of the New England orogenic belt (Voisey, 1959, p. 192).

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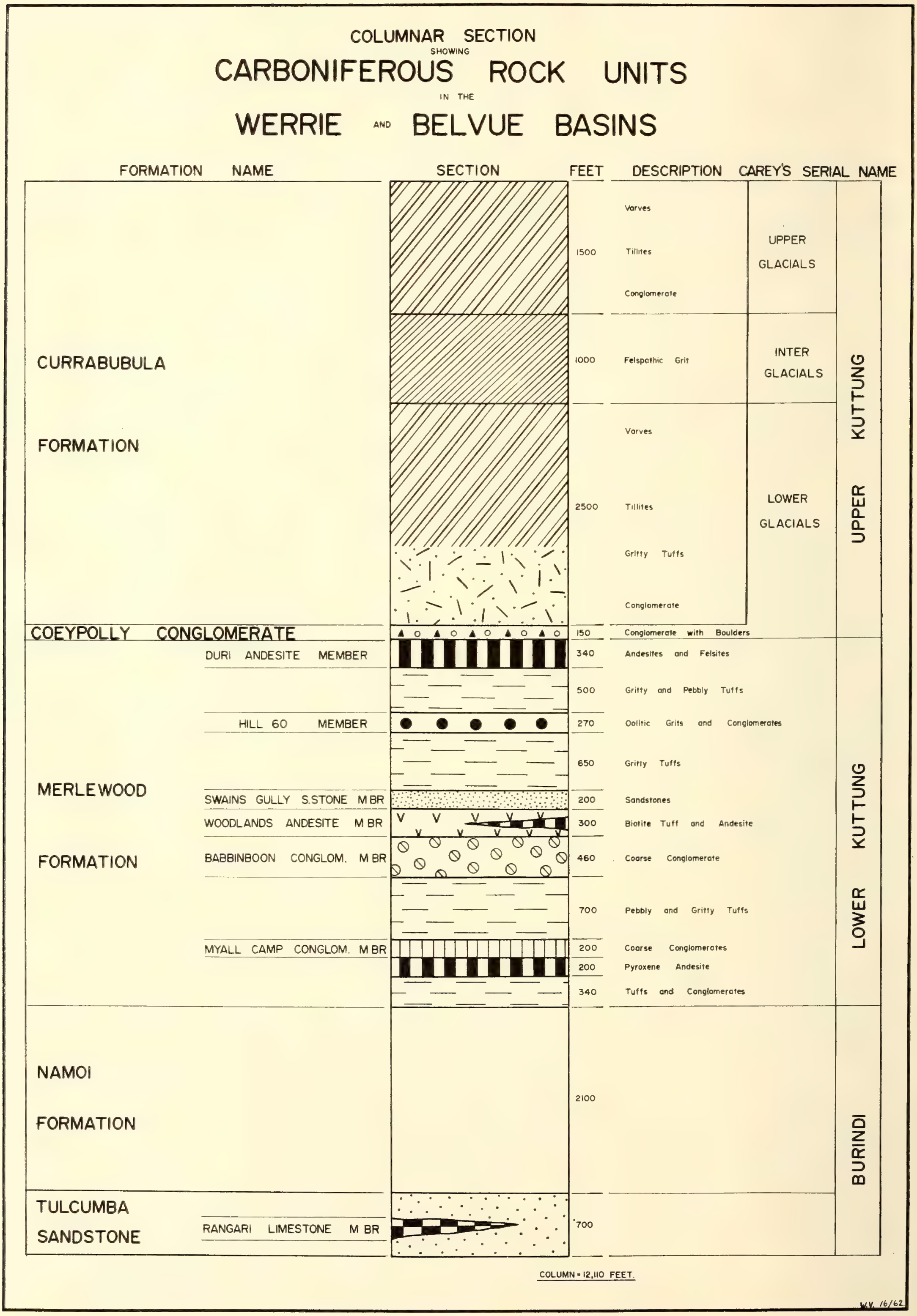
COLUMNAR SECTION
SHOWING
CARBONIFEROUS ROCK UNITS
IN THE
WERRIE AND BELVUE BASINS
FORMATION NAME
SECTION
FEET
DESCRIPTION
CAREY'S SERIAL NAME
CURRABUBULA FORMATION
Varves
1500
Tillites
Conglomerate
UPPER GLACIALS
1000
Felspathic Grit
INTER GLACIALS
Varves
2500
Tillites
Gritty Tuffs
Conglomerate
LOWER GLACIALS
UPPER KUTTUNG
COEYPOLLY CONGLOMERATE
150
Conglomerate with Boulders
MERLEWOOD FORMATION
DURI ANDESITE MEMBER
340
Andesites and Felsites
500
Gritty and Pebbly Tuffs
HILL 60 MEMBER
270
Oolitic Grits and Conglomerates
650
Gritty Tuffs
SWAINS GULLY S.STONE M BR
200
Sandstones
WOODLANDS ANDESITE M BR
300
Biotite Tuff and Andesite
BABBINBOON CONGLOM. M BR
460
Coarse Conglomerate
700
Pebbly and Gritty Tuffs
MYALL CAMP CONGLOM. M BR
200
Coarse Conglomerates
200
Pyroxene Andesite
340
Tuffs and Conglomerates
LOWER KUTTUNG
NAMOI FORMATION
2100
BURINDI
TULCUMBA SANDSTONE
RANGARI LIMESTONE M BR
700
COLUMN = 12,110 FEET.
W.V. 16/62.

FIG. 1

The earliest references to the geology of the area followed visits by Professor T. W. E. David and the Government Geologist E. F. Pittman early in the century. H. I. Jensen (1907) made a study of the Nandewar Mountains and assigned most of the strata to the Carboniferous, Devonian rocks not having been recognized in the vicinity at the time. The foundation upon which later work has been based was laid by W. N. Benson (1913 *et seq.*), who mapped the area between Warialda and Nundle. A. C. Lloyd (1933) conducted a reconnaissance of the area and S. W. Carey (1934, 1935, 1937) dealt with the stratigraphy of the Werrie Basin which lies immediately to the south. F. N. Hanlon (1948) included the western portion of the area in Part VI of his " Geology of the North Western Coalfield ".

Since completion of the mapping the Keepit Dam has flooded a large part of the country approximately in the centre of the map (Fig. 3).

Devonian Stratigraphy

MANILLA GROUP

The division of the Upper Devonian sequence or " Barraba Series " (David, 1950, pp. 251–252) has been discussed recently by K. A. W. Crook (1961*b*, p. 192) and B. C. Chappell (1962, pp. 66–69) following Voisey's interpretation of W. N. Benson's divisions in the Manilla-Barraba region (1958*b*, pp. 209–210).

The relationships between the units in the Manilla Group are different on the opposite sides of the Belvue Syncline.

As the results of field work, at present in progress throughout the Nundle-Warialda belt, are required before the problem can be resolved, the Manilla Group is marked as " undifferentiated " on the map (Fig. 3). The Keepit Conglomerate and Borah Limestone are tentatively regarded as members of the Mandowa Mudstone. One or both could assume formation status later.

Although it is possible that the lowest parts of the Devonian sequence could extend below the base of the Manilla Group into the Tamworth Group (Crook, 1961*a*, p. 176), final confirmation is required from T. B. H. Jenkins, who is concerned with detailed mapping of the area west of Keepit Dam.

Keepit Conglomerate Member. From the Merlewood Section, Carey (1937, p. 349) described the Upper Devonian beds as becoming progressively more bouldery and culminating in a very variable bed about 800 feet thick, best described as an agglomerate. Some phases, however, are true conglomerates with well-worn boulders of andesitic lava. In places the matrix is entirely tuffaceous. This horizon can be traced to the Keepit Dam and for some miles north of it where it gradually breaks up and the conglomerate phase disappears. This unit is here defined as the Keepit Conglomerate member. It is separated from the Tulcumba Sandstone by a variable thickness of mudstone which is characterized by abundant specimens of *Leptophloeum australe.* This mudstone is well exposed, in the gutter on the north of the road west of the Keepit Road turnoff from the Oxley Highway, where it is 200 feet thick. The Borah Limestone has not been found within this part of the sequence.

Borah Limestone Member. The Borah Limestone was named by J. W. Pickett (1960, p. 237) after its occurrence in the valley of Borah Creek, near the bend in the road shown in the north-east corner of the map (Fig. 3). Unfortunately faulting prevented him from placing it in position in a sequence in the type locality, but it is the same limestone which has been found at intervals along the broken eastern limb of the Belvue Basin. It occurs below the mudstones which underlie the Tulcumba Sandstone and above somewhat similar mudstones rich in *Leptophloeum australe.* Its position is thus near the top of the Upper Devonian Manilla Group.

The limestone is fine-grained, blue grey in colour, weathering to white and it contains crystallized radiolarian tests and euhedral crystals of an unknown mineral which has been replaced by a mosaic of albite and calcite. The bed in the type area is only 3 to 4 feet in thickness. Pickett described a new species of clymeniid, *Cymaclymenia borahensis* which has been found abundantly in the northern occurrences of the limestone.

Carboniferous Stratigraphy

The Carboniferous rocks of the Werrie Basin were excellently mapped by S. W. Carey (1934, 1935, 1937) before the Australian Code of Stratigraphical Nomenclature was introduced. It is proposed here to give names to the units which he mapped which conform to the Code, and to define them in relation to the sections which he measured. Consequently, this publication should be read in conjunction with Carey's papers on the Werrie Basin. The names used for the formations have been chosen from geographical names mentioned by him and are indicated on the columnar section (Fig. 1).

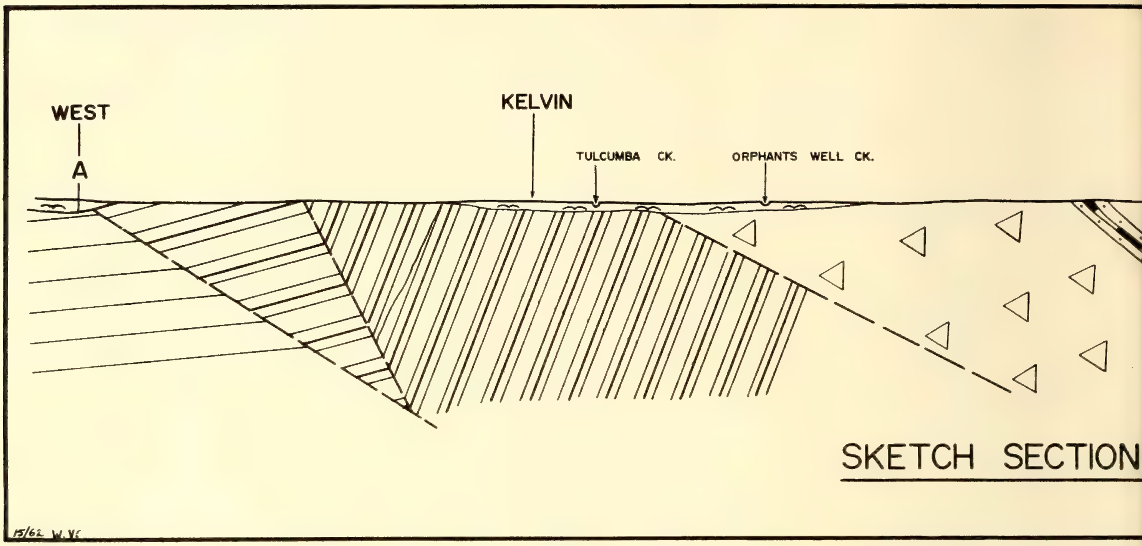

FIG. 2

The legend of Carey's Geological Map of the Werrie Basin should be amended as below and the units shown on it will then conform to the Code.

Carey's Legend	Proposed Amendment
Alluvials	Alluvium
Upper Coal Measures	Werris Creek Coal Measures
Werrie Traps	Werrie Basalts
Lower Coal Measures	Willow Formation
Glacial Stage	Currabubula Formation
Lower Kuttung	Merlewood Formation
Burindi Series	Namoi Formation together with Tulcumba Sandstone
Barraba Series	Manilla Group
Porphyry Boulder Horizon	Coeypolly Conglomerate
Acid Lavas	Acid Lavas
Hornblende Andesite	Hornblende Andesite
Pyroxene Andesite	Pyroxene Andesite
Warrigundi Intrusives	Warrigundi Intrusives
Tertiary Basalt	Tertiary Basalt

The same units as far as they have been recognized are shown on the present map (Fig. 3), which extends knowledge of their outcrops to the north-west of the Werrie Basin.

The Merlewood Formation has a number of important rock units, some of which are shown on Carey's map (1937, plate XVIII). These are (in descending order):

Duri Andesite
Hill 60 Member
Swain's Gully Sandstone Member
Woodland's Andesite Member
Babbinboon Conglomerate Member
Myall Camp Conglomerate Member.

The Myall Camp Conglomerate and Babbinboon Conglomerate can be seen beside the andesites in the south. The Woodlands Andesite peters out to the north with the Babbinboon Conglomerate. The Swain's Gully Sandstone and Hill 60 Member are stippled. The Duri Andesite is more prominent on the eastern limb of the Werrie Basin and can be recognized as being the major pyroxene andesite which shows prominently on Carey's map (1934, plate XVII).

The stratigraphical units will now be defined in the manner suggested by the Australian Code of Stratigraphical Nomenclature (Raggatt, 1956).

TULCUMBA SANDSTONE

Derivation: Parish of Tulcumba, County of Nandewar.

Type Section: Swain's Gully, described as Merlewood section by Carey (1937, p. 350).

Lithology: Cross-stratified felspathic sandstones, conglomerates, dark blue marly mudstones, tuffs and oolitic limestones.

Thickness: Type-section 700 feet is in Swain's Gully and includes 400 feet of Carey's "basal series" and 300 feet dark blue marly mudstone sand tuffs.

RANGARI LIMESTONE MEMBER

Derivation: Rangari Station, parish Rangari, County Nandewar.

Type Section: Along Manilla-Boggabri road, one mile east of Rangari Homestead.

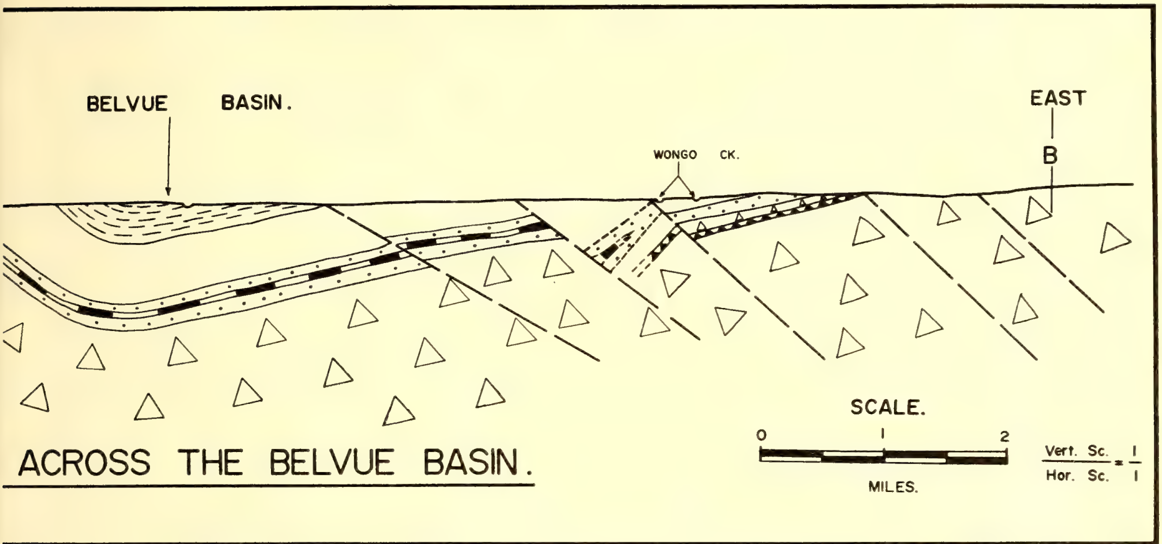

FIG. 2—*continued*

Lithology: Oolitic limestone in part bioclastic.

Thickness: Type-section 15 feet, lensing southward and not reaching the type-section of the Tulcumba sandstone at Merlewood.

The basal unit of the Carboniferous sequence, the Tulcumba Sandstone, differs considerably from the underlying Devonian mudstone containing *Leptophloeum australe* and regarded as typical of the Manilla Group. In the type section Carey noted that the unit started with a basal conglomerate with boulders of granite, hornfels and porphyrite measuring as much as ten inches in diameter. The overlying buff-coloured sandstones are current-bedded—a characteristic which enables the Tulcumba Sandstone to be recognized for many miles to the north. The typical sandstone consists almost entirely of quartz and feldspar, the latter predominating. In addition, there are fragments of felsitic rock and occasional flakes of biotite. The cement is mostly clay but in some places calcite is important. Sorting and rounding of the fragments is good. The presence of the gritty phase is mostly due to the felsitic rock fragments which attain a maximum diameter of 2 mms., whereas the mean diameter of the sandstone phase is seldom greater than 0·5 mm.

The Rangari Limestone member which has not been found in the Swain's Gully section is well exposed on either side of the Tamworth-Gunnedah road near the Keepit Dam turnoff. Here it is 15 feet thick and is 20 feet below the top of the sandstone formation. It outcrops continuously to a short distance beyond the northern boundary of the map. K. S. W. Campbell (verbal communication) remeasured the Swain's Gully section and has extended the thickness of the Tulcumba Sandstone unit to 700 feet including the *Cladochonus tenuicollis* and *Phillipsia* sp. bed.

The Tulcumba Sandstone thins northward and beyond the Wean-Manilla road (north-east of Rangari Homestead) it is only 250 feet thick. The Rangari Limestone, here is 10 feet in thickness and commences 50 feet from the base of the formation. Another limestone lens 15 feet thick, composed largely of bioclastic materials and containing 2 feet of very fossiliferous siltstone, occurs near the top of the sandstone.

In thin section the Rangari Limestone is seen to consist largely of detrital feldspar or felsitic rock fragments. Quartz is absent or poorly represented. The feldspar is in the Ab_{80}-An_{20} to Ab_{40}-An_{60} range and is mostly Ab_{65}-An_{35} in composition. The oolitic portions consist of minute nuclei and accretionary calcite set in a dominantly crystalline calcite matrix. The nuclei are, for the most part, small fragments of euhedral feldspar or fossil debris.

Namoi Formation

Synonymy: Burindi Series (in part) (Benson, 1915*b*), Lower Burindi Group (in part) (Voisey, 1952).

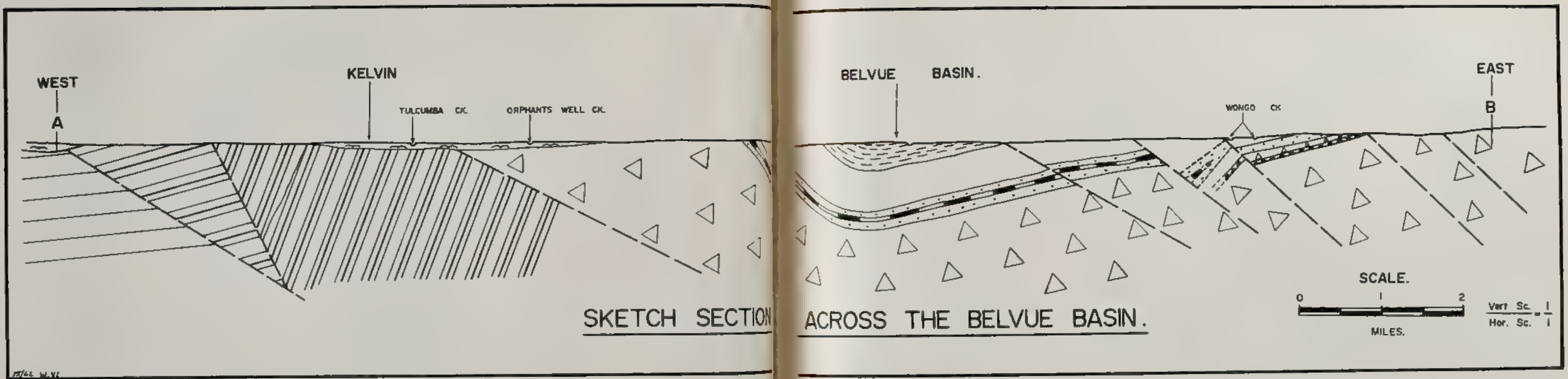

FIG. 2 — FIG. 2—*continued*

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Lithology: Cross-stratified felspathic sandstones, conglomerates, dark blue marly mudstones, tuffs and oolitic limestones.

Thickness: Type-section 700 feet is in Swain's Gully and includes 400 feet of Carey's "basal series" and 300 feet dark blue marly mudstone sand tuffs.

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Derivation: Rangari Station, parish Rangari, County Nandewar.

Type Section: Along Manilla-Boggabri road, one mile east of Rangari Homestead.

Lithology: Oolitic limestone in part bioclastic.

Thickness: Type-section 15 feet, lensing southward and not reaching the type-section of the Tulcumba sandstone at Merlewood.

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Namoi Formation

Synonymy: Burindi Series (in part) (Benson, 1915*b*), Lower Burindi Group (in part) (Voisey, 1952).

Type Section: Swain's Gully, described as Merlewood Section by Carey (1937, p. 350) as "typical Burindi facies".

Lithology: Mudstones, limestones, sandstones and conglomerates.

Thickness: Type-section 2,100 feet.

In the type-area of Swain's Gully the Namoi Formation consists of olive-green mudstones with lenses of sandstone and oolitic limestone. Further north more sandstone beds and some heavy conglomerate lenses are conspicuous. Because of the great variety of rock types the name "formation" was chosen in preference to "mudstone", though this rock is dominant in most parts of the sequence.

J. W. Pickett (unpublished thesis) has described some sandstone bands, grey or greenish grey in hand-specimens. They are usually less than a foot in thickness, but are quite variable for they may exceed ten feet in places, apparently thickening from west to east.

Microscopically, they are seen to contain very little quartz—usually less than 5 per cent, but with feldspar and/or rock fragments often comprising three-quarters of the rock. The matrix is nearly always in excess of 20 per cent. The rock fragments are almost invariably lavas, of acid and intermediate types. There is a wide range in the composition of the feldspars. Chlorite replaces many lithic fragments, epidote is in small crystals elongated and lying in the cleavage traces, while calcite occurs in small islands of irregular shape in the plagioclase grains.

Carey (1937, p. 350) stated that the Burindi Series was more than 2,500 feet thick. K. S. W. Campbell has a measured thickness of the Namoi Formation in the Swain's Gully-Babbinboon area of just over 3,000 feet.

Merlewood Formation

Synonymy: Lower Kuttung Series (Carey, 1937).

Derivation: Merlewood Homestead.

Type Section: Merlewood Section (Carey, 1937, pp. 350–351).

Lithology: Lithic sandstones and conglomerates. Material often current-bedded and largely of volcanic origin. Lavas, commonly pyroxene andesite, are interbedded.

Thickness: Type-section 3,350 feet.

The Merlewood Formation is adequately described by Carey as the "Lower Kuttung Series". His map (plate XVIII) shows a number of rock units which are here given the status of members of the formation. These are listed below. Carey's descriptions of the rocks appear to be adequate and as they were not examined in detail in the Belvue Basin they will not be dealt with further.

Outcrops in the Belvue Basin are discontinuous and poor but pebbles are widespread and apparently come from the lower beds of the formation. None of the members apart from the conglomerates was recognized.

Members of Merlewood Formation

All defined from Swain's Gully or Merlewood Section (Carey, 1937, pp. 350–351).

(1) Myall Camp Conglomerate Member

Derivation: Myall Camp Gully.

Lithology: Coarse conglomerates with boulders of pink granite and porphyry, lithic sandstones.

Thickness: Type-section 200 feet.

(2) Babbinboon Conglomerate Member

Derivation: Parish of Babbinboon, County of Buckland.

Lithology: Thick conglomerates with granite and andesite boulders up to 2 feet in diameter and coarse lithic sandstones.

Thickness: Type-section 460 feet.

(3) Woodlands Andesite Member

Derivation: Woodlands Station.

Lithology: Pyroxene Andesite.

Thickness: Type-section 20 feet but thickening elsewhere to 300 feet.

(4) Swain's Gully Sandstone Member

Derivation: Swain's Gully, Parish of Babbinboon, County of Buckland.

Lithology: Pebbly and coarse gritty lithic sandstone with plant fossils.

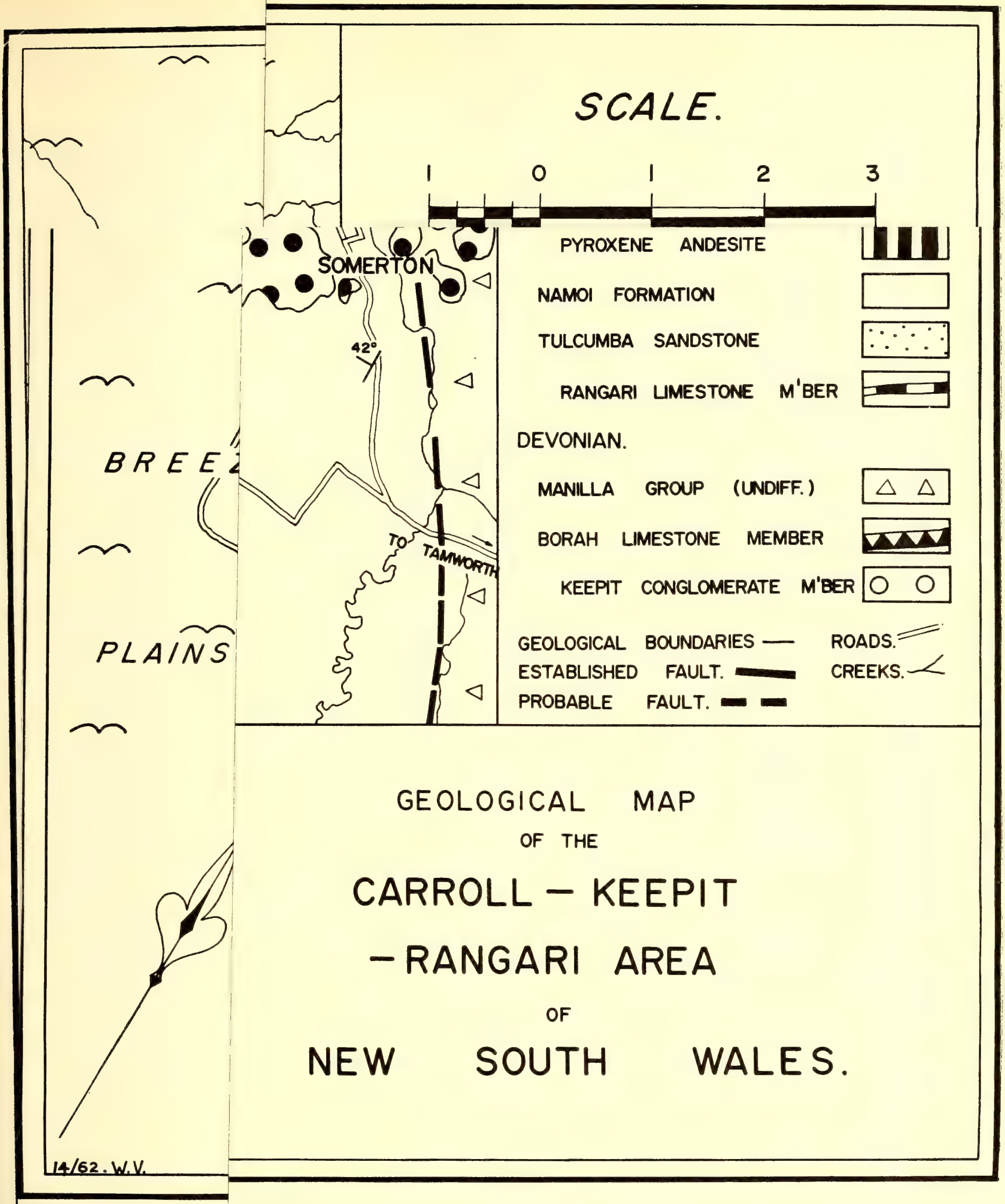
Thickness: Type-section 200 feet.

(5) Hill 60 Member

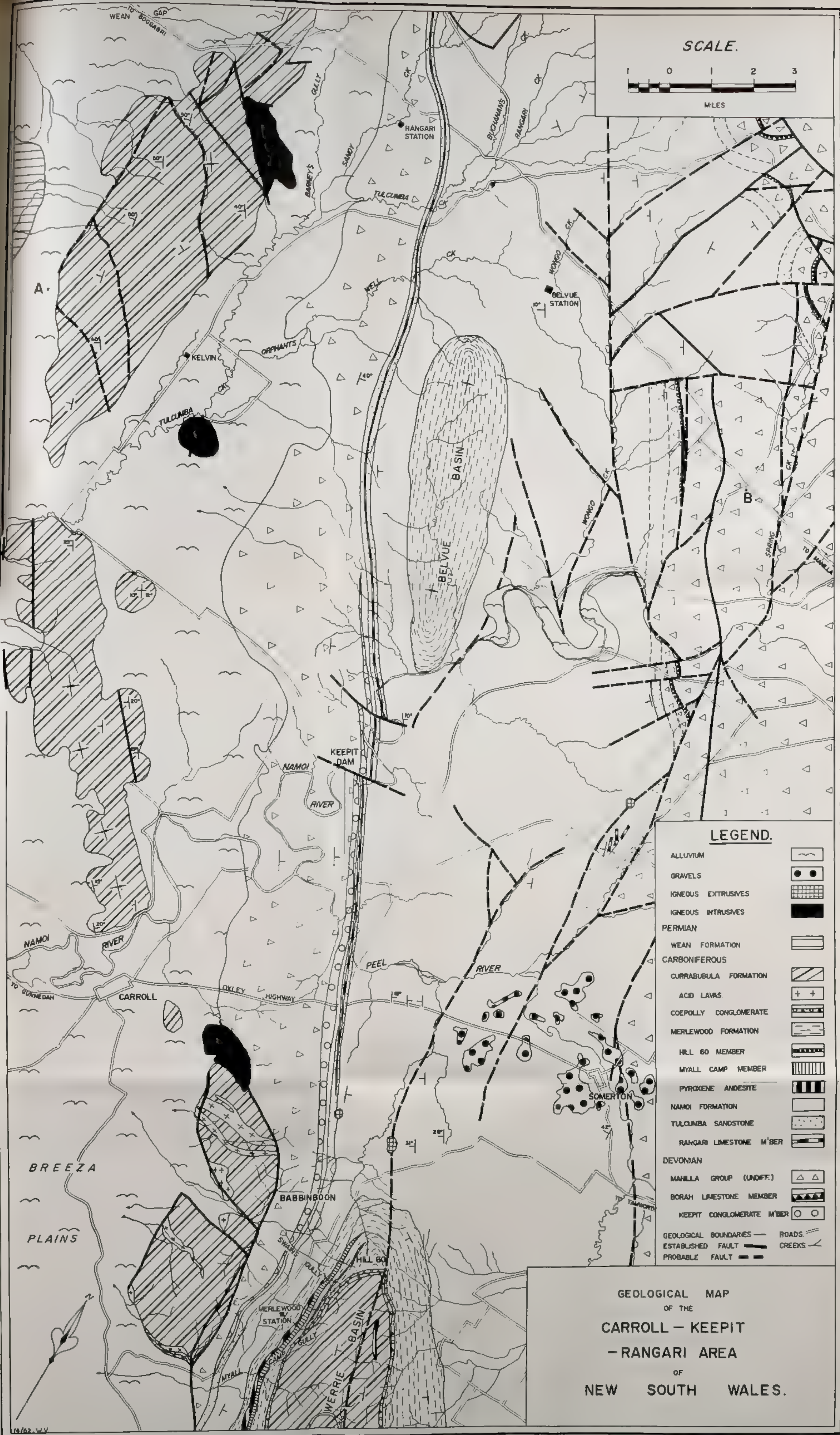
Derivation: Portion 60, Parish of Babbinboon, County of Buckland.

Lithology: Conglomerate with grey quartzite pebbles and volcanics in a matrix containing a variable amount of oolitic limestone.

Thickness: Type-section 270 feet.



SCALE.
1 0 1 2 3
PYROXENE ANDESITE
NAMOI FORMATION
TULCUMBA SANDSTONE
RANGARI LIMESTONE M'BER
DEVONIAN.
MANILLA GROUP (UNDIFF.)
BORAH LIMESTONE MEMBER
KEEPIT CONGLOMERATE M'BER
GEOLOGICAL BOUNDARIES
ESTABLISHED FAULT.
PROBABLE FAULT.
ROADS.
CREEKS.
SOMERTON
42°
TO TAMWORTH
BREEZ
PLAINS
GEOLOGICAL MAP
OF THE
CARROLL — KEEPIT
— RANGARI AREA
OF
NEW SOUTH WALES.
14/62. W.V.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WEAN FORMATION
CARBONIFEROUS
CURRABUBULA FORMATION
ACID LAVAS
COEPOLLY CONGLOMERATE
MERLEWOOD FORMATION
HILL 60 MEMBER
MYALL CAMP MEMBER
PYROXENE ANDESITE
NAMOI FORMATION
TULCUMBA SANDSTONE
RANGARI LIMESTONE M'BER
DEVONIAN
MANILLA GROUP (UNDIFF.)
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OF THE
CARROLL – KEEPIT
– RANGARI AREA
OF
NEW SOUTH WALES.
WEAN
TO BOGGABRI
GAP
RANGARI STATION
TULCUMBA
BELVUE STATION
KELVIN
BELVUE BASIN
KEEPIT DAM
NAMOI RIVER
PEEL RIVER
OXLEY HIGHWAY
TO GUNNEDAH
CARROLL
SOMERTON
TO TAMWORTH
TO MANILLA
BREEZA
PLAINS
BABBINBOON
HILL 60
MERLEWOOD STATION
WERRIE BASIN
MYALL CAMP GULLY
SWAINS GULLY
A.
B
N

(6) Duri Andesite Member

Derivation: Duri Peak.

Lithology: Volcanic rocks principally pyroxene andesites, felsites and tuffs.

Thickness: Type-section 340 feet, but thickens to 1,000 feet elsewhere.

Coeypolly Conglomerate

Synonymy: Porphyry Boulder Horizon.

Derivation: Coeypolly Creek, County of Buckland.

Type Area: Royston Section (Carey, 1937, p. 348).

Lithology: Coarse conglomerate with boulders of granite and a distinctive pink porphyry.

Thickness: Type-area 150 feet.

This "Porphyry Boulder Horizon" was described by Carey as the basal conglomerate of the Upper Kuttung Series. His mapping of it round the Werrie Basin seems sufficient for it to be regarded as a formation.

Currabubula Formation

Synonymy: Glacial beds of Upper Kuttung.

Derivation: Village of Currabubula.

Type Section: Woodlands section Werrie Basin (Carey, 1937, pp. 343–344), but well exposed and easy to observe in creek through Currabubula village.

Lithology: Tillites, conglomerates, varves and tuffs with some flows of acid lava.

Thickness: Type-section 5,000 feet.

The beds of the Currabubula Formation, described by Carey (1937, p. 344), are regarded as overlying the coarse basal Coeypolly Conglomerate and with it comprising what he called the "Upper Kuttung Series".

Rocks of the Currabubula Formation were found in the ranges running north-westward from Carroll to Wean Gap. The varves and associated beds are exposed along the creek through the Gap.

Permian Stratigraphy

Nandewar Group

F. N. Hanlon (1948, p. 256) divided the Nandewar Group into the Wean Formation and the overlying Vickery Conglomerate. The Wean Formation, of fresh-water origin, was tentatively correlated with the Greta Coal Measures, in the north-west corner of the map west of the Border Thrusts and lying almost horizontally upon the cratonic block.

In suggesting the alteration in the Permian portion of the legend on Carey's 1934 map (plate XVII) it is considered that the "Werris Creek Coal Measures" is a name which is a suitable rock term. The name of "Werrie Basalts" is preferred to "Werrie Traps" because the word "trap" is now rarely used for basalt in New South Wales and furthermore local New England usage includes a variety of rocks other than basalt and granite.

It is here recommended that the rocks outcropping widely throughout the Werrie Basin and to the south, regarded by Carey (1934) as probably of "Lower Coal Measure" age, and taken to comprise the "Lower Stage" of the "Willow Series" by Hanlon (1947, p. 281) be called the Willow Formation, of thickness 300–350 feet, with the type section at Currabubula in Currabubula Creek.

Igneous Rocks

A number of intrusions of basic rock related to those described by Carey (1934, pp. 369–372) occur along the line of the main faults on the inner side of the Border Thrusts. They have not yet been studied in detail. Small outliers of Tertiary basalt occur sporadically throughout the area mapped.

Structural Geology

The area is within the Western Belt of Folds and Thrusts and includes the Border Thrusts of the Upper Palaeozoic Orogenic Belt of north-eastern New South Wales (Voisey, 1959) and is south-west of the Manilla Syncline (Voisey, 1958*b*). Chappell (1962) has mapped the structures immediately to the east. The western cratonic areas with Permian and Mesozoic rocks lying with very gentle westerly dips on the stable block have been mapped by Hanlon (1947 *et seq.*).

The most important controlling structure is the synclinal axis with its reverses of pitch which gave rise to the Werrie Basin (Carey, 1934) in the south and the Belvue Basin which is shown in the central portion of the map (Fig. 3).

The Belvue Basin is asymmetrical—the eastern limb dipping west generally at angles of from 10° to 15° and the western limb dipping east generally at about 40° (Fig. 2).

Faults occur in the closure portions at both the northern and southern ends of the basin, the actual extent of the fracturing being greater than the map indicates as a large number of minor faults occur in the soft mudstones of the

Namoi Formation. These are difficult to portray adequately.

An extraordinary feature of the pattern is the continuity of the Tulcumba Sandstone, which deviates little from its position on the western limb of the Werrie Basin to take up a similar one in the Belvue Basin. On the other hand it is extensively broken and displaced along the eastern limb of the latter. North of Somerton there is the suggestion that it occupies the extensively fractured core of an anticline. Fragments of what is probably the Rangari Limestone member are displaced from one another and dip in various directions.

A large number of faults can be traced through competent units of the Manilla Group to the east, giving rise to a pattern similar in style to that in the neighbouring Manilla Syncline. The major thrusts are south-south-east to north-north-west in their trend and roughly parallel to the Border Thrusts and main axes of folding. The minor faults between them have displaced the useful marker bed—the Borah Limestone—in a number of places. The fragments of this bed can be traced from this area past Somerton to the south of Tamworth, where it has been mapped by Crook (1961*a*. 1961*b*) as the Kiah Limestone.

Two main thrusts and a number of minor ones belong to the Border Thrust zone and are continuations of those (the Mooki Thrusts) noted by Carey in the south. An elongated area between the thrusts is composed almost entirely of Currabubula Formation (Upper Kuttung) and forms a prominent physiographical feature. Carey (1934, pp. 359–369) discussed the tectonics of the western part of the Werrie Basin and his remarks apply similarly to the Carroll-Wean belt. It is noteworthy, however, that the Currabubula Formation between the thrusts in the south is folded into an anticline.

Conclusion

The material in this paper has been assembled as part of a major project, shared by a number of workers, aimed at mapping the Devonian and Carboniferous strata throughout the New England region. The identification of mappable units has been closely related to the recognition of the structures. Use of aerial photography has shown that faulting is far more widespread than was formerly believed and selection of places where sections can be measured with confidence is a major difficulty. Consequently, earlier stratigraphical work carried out without this advantage has of necessity been critically examined.

We wish to thank Dr. K. S. W. Campbell of the School of General Studies of The Australian National University and Dr. G. M. Philip of the University of New England for assistance in reading of the manuscript. In connection with the field work we much appreciated the hospitality of Mr. and Mrs. Bruce Dowe, Mr. and Mrs. G. Gordon and family, Mr. and Mrs. R. Perrott, and Mr. and Mrs. C. Nicholls.

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ROYAL SOCIETY OF NEW SOUTH WALES

VOLUME 97 1964 PART 3

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The Eclogite-bearing Basic Igneous Pipe at Ruby Hill near Bingara, New South Wales

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Abstract—The Ruby Hill pipe, 12 miles south of Bingara, N.S.W., intrudes Upper Devonian Baldwin sediments and is composed of basic breccia intruded by several alkali olivine-basalt dykes. A palaeomagnetic study suggests a Mesozoic age for the intrusion. Of particular petrogenetic interest is the occurrence in the breccia and dykes of a varied assemblage of inclusions which may represent portions of lower crust (granulitic inclusions) or upper mantle (eclogitic and rare ultrabasic inclusions) caught up by the magma prior to its intrusion in the upper crust. The granulites are coarse-grained assemblages of garnet ($n=1\cdot766$), clinopyroxene ($\beta=1\cdot700$, $2V\gamma=59°$), plagioclase (An_{71}) plus minor amounts of scapolite and rutile. The scapolite (close to Me_{70}) has a high sulphur content (approximately $2\cdot3$ per cent S). The eclogites consist of pyrope-rich garnet and clinopyroxene ($\beta=1\cdot708$, $2V\gamma=58°$) with minor rutile.

Introduction

Ruby Hill forms a low hill (about 80 feet high) some 12 miles south of Bingara on the western side of Bingara-Barraba road. Curran (1896) first reported the occurrence of a red pyrope-rich garnet in a " coarsely crystallizing basic rock " within the basalt occurring at Ruby Hill. The garnet matrix was described as a probable segregation from the basalt and was composed of " pyroxene, feldspar and kelyphite rings of a composite substance surrounding garnet ". Considerable interest in Ruby Hill was aroused by a report that ten diamonds totalling $4\frac{1}{8}$ carats were found in the breccia filling of the Ruby Hill igneous pipe (Pittman, 1901) but no further diamonds were ever recovered from the breccia.

In 1902 Card published a detailed petrological discussion of the inclusions in the basic breccia and basalt dykes at Ruby Hill and described them as mostly " eclogites " with some " augite picrites ". The present study of the Ruby Hill pipe and its inclusions arose from the renewed petrological interest in eclogitic rocks as possible materials composing the earth's upper mantle (Lovering, 1958). Eclogites occurring as inclusions within igneous pipes are particularly important in that they may well represent direct samples of the upper mantle caught up in the magma of the pipe during its passage to the earth's surface.

The Nature of the Intrusion

The form of the Ruby Hill igneous pipe is essentially that described by Pittman (1901) and shown in his sketch map. The main part of the roughly circular pipe is composed of a rather decomposed, brownish volcanic breccia of generally basic composition intruded by three large and at least two smaller dykes composed of a very fine grained basaltic rock. The inclusions occur in both the breccia and the basaltic dykes, but those occurring within the breccia tend to be very much more altered with very little garnet remaining. The pipe itself intrudes greywackes and mudstones of the Upper Devonian Baldwin formation and many inclusions of these rocks occur within the breccia. The " eclogite " and ultra-basic inclusions occur in both the breccia and the basalt dykes but those within the breccia are always very much altered.

The large (up to 1 cm. across) ruby-red garnet xenocrysts described by Curran (1896) and Card (1902) occur in both the breccia and basalt. An old analysis reported by Curran (1896) is given in Table 1 and a calculation of the structural formula would suggest that it is not a first-class analysis. However, the analysis is of sufficient accuracy to establish that the garnet contains over 50 mol. per cent pyrope and has probably resulted from the break-up of garnet granulite and/or eclogite inclusions in the pipe.

TABLE 1
Garnet Xenocrysts in Ruby Hill Breccia Pipe
(After Curran, 1896)

Analysis		Structural Formula (calculated on the basis of 24 (O))		
SiO_2	39·57	Si		6·02
Al_2O_3	23·68	Al	4·24	4·26
Fe_2O_3	0·18	Fe^{3+}	0·02	
FeO	10·04	Mg	3·28	6·46
MnO	3·76	Fe^{2+}	1·28	
MgO	14·45	Mn	0·48	
CaO	8·76	Ca	1·42	
Total	100·44			
D	3·743			

Almandine	19·7 mol. %
Andradite	0·4
Grossular	21·7
Pyrope	50·7
Spessartine	7·5

THE BRECCIA

Superficially, the breccia resembles the so-called " yellow ground " of the weathered zone of the South African diamond bearing pipes. However, it is obvious that the Ruby Hill breccias are generally of basic composition and quite different from the curious volatile rich, ultra-basic kimberlite magmas of the South African pipes. The Ruby Hill breccia does however very closely resemble the basic breccia in the eclogite-bearing pipes occurring near Delegate, New South Wales (Lovering, unpublished work). One unusual feature of the Ruby Hill occurrence is the abundance of very pale pink stilbite filling vughs and veins within the breccia.

The breccia is full of fragments of various sedimentary and igneous rocks (from the surrounding country rocks) together with many fragments of basaltic rocks. The granulitic and eclogitic inclusions are much less abundant but this may be due to the fact that they are usually very altered and difficult to recognize. The breccia also contains abundant red garnet and green chrome-diopside grains and probably a considerable variety of other mineral grains derived both from the country-rock inclusions and the more deep-seated inclusions.

THE BASALT DYKES

Basaltic fragments are common in the breccia but the least altered basalts occur as dykes within the breccia. In hand specimen the dyke basalts are generally very fine grained, occasionally rather mottled in appearance and containing many garnet xenocrysts and granulite and eclogite xenoliths.

In thin section there are a number of " phenocrysts " (up to 1 mm. across) of clino-pyroxene (type I) with border zones of a second clino-pyroxene (type II) which shows virtual optical continuity with the central clino-pyroxene and gives a well defined crystal shape to the " phenocrysts ". The type I clino-pyroxene is usually irregular in shape, colourless and has a very low dispersion (high 2V). On the other hand the surrounding type II clino-pyroxene has very strong dispersion with a 2V of approximately 33° and is probably salitic in composition. It would seem that the clino-pyroxene forming in the groundmass of the rock is also salitic in composition so that the type II clino-pyroxene represents a salitic clino-pyroxene which crystallized from the magma on to a nucleus of a different sort of clino-pyroxene (type I) which probably is xenocrystic material resulting from the break-up of various deep-seated inclusions in the magma. As such these " phenocrysts " are both xenocrystic and phenocrystic in origin. " Microphenocrysts " of olivine occur showing all stages in alteration to serpentine. It is also possible that at least some of the olivine occurring in the rock is also xenocrystic in origin, resulting from the break-up of ultra-basic xenoliths in the magma. Some brown spinel xenocrysts showing dark borders were also observed and probably originated from ultra-basic xenoliths.

The groundmass consists of small ($<0·1$ mm.) plagioclase laths (often showing fluidal texture), salitic clino-pyroxene grains and is dusted with extremely small opaque grains about 2μ across. There is also a considerable amount of brown glass ($n>1·54$) in the groundmass. Serpentinous and chloritic material also was observed. The analysis of the basalt (Table 2) indicates that the molecular norm contains a considerable amount of nepheline ($\sim 8\%$) although none was observed in the mode. It would seem that the magma filling the dykes in the Ruby Hill breccia was an alkaline olivine basalt type.

The basalt also contains xenocrysts of a strongly magnetic black mineral with a sub-metallic lustre. A partial analysis (Table 3) indicates that it is a titanomagnetite with some Fe^{3+} being replaced by Al^{3+} and Cr^{3+} and Fe^{2+} by some Mg^{2+} and Mn^{2+}.

AGE OF THE INTRUSION

In the absence of any more positive evidence, the Ruby Hill intrusion has usually been considered to belong to the Tertiary alkaline

Table 2

Chemical Analyses of Rocks from the Ruby Hill Pipe

	"Eclogite" (Garnet Granulite) Inclusion (Card, 1902)	Garnet Granulite Inclusion R165 (Altered)	Eclogite (Altered) Inclusion R169	Basalt Dyke R176
SiO_2	43·05	44·30	43·46	46·25
TiO_2	trace	0·94	2·36	2·16
Al_2O_3	20·74	18·62	14·49	15·80
Fe_2O_3	4·55	5·35	7·49	5·53
FeO	4·08	4·04	4·62	6·12
MnO	0·23	0·13	0·14	0·24
MgO	7·06	8·63	7·59	3·81
CaO	15·30	14·52	14·57	7·94
Na_2O	1·59	1·33	1·64	4·54
K_2O	0·21	0·07	0·16	2·40
P_2O_5	0·02	0·04	0·07	0·87
H_2O+	2·97	1·65	2·13	2·10
H_2O-	0·50	0·24	1·31	0·47
CO_2	—	0·35	0·28	0·16
Cr_2O_3	—	0·05	0·02	0·02
Total	100·30	100·25	100·32	100·41
S.G.	—	3·08	2·93	2·81
Molecular Norm				
Quartz	—	—	0·02	—
Orthoclase	1·24	0·41	0·95	14·18
Albite	6·84	11·25	13·88	24·69
Anorthite	48·84	44·63	31·71	15·65
Diopside	21·44	19·57	29·85	13·51
Fs	1·95	0·67	0·00	1·27
En	8·24	8·49	13·84	5·19
Wo	11·25	10·41	16·01	7·12
Hypersthene		7·23	5·06	
Fs	—	0·53	0·00	—
En	—	6·70	5·06	—
Olivine	8·26	4·80		8·25
Fa	1·71	0·38	—	1·75
Fo	6·55	4·42	—	6·50
Apatite	0·05	0·09	0·17	2·06
Magnetite	6·60	7·76	8·48	8·02
Ilmenite	—	1·79	4·48	4·10
Hematite	—	—	1·64	—
Chromite	—	—	0·03	0·03
Nepheline	3·58	—	—	7·99
Water	3·47	1·89	3·44	2·57
Analyst:	H. P. White	A. J. Easton	A. J. Easton	A. J. Easton

olivine basalt province of New South Wales. Many of the flow basalts belonging to this province overlie Tertiary plant-bearing sediments and so are Tertiary in age (David and Browne, 1950), but recently a palaeomagnetic study of three supposedly Tertiary intrusions (i.e. Prospect, Mt. Gibraltar and Gingenbullen) has indicated that they are of Mesozoic age (Boesen, Irving and Robertson, 1961). More recently, potassium-argon dating has shown that the Prospect intrusion is 168 million years old while Mt. Gibraltar is 178 million years old, in good agreement with the palaeomagnetic data (Evernden and Richards, 1962).

The Ruby Hill breccia does not seem to contain any minerals suitable for K-Ar dating but a palaeomagnetic study has been made on the basalt dyke within the breccia and a south pole position of approximately 49° S, 190° E

TABLE 3

Partial Analysis of Titano-magnetite Xenocryst in Basalt from Ruby Hill

TiO_2	7·36
Al_2O_3	2·61
Fe_2O_3*	88·1
Cr_2O_3	0·04
MnO	0·3
MgO	0·8
	99·2
D	4·90

Analyst : A. J. Easton.
* Total iron reported as Fe_2O_3.

has been determined (W. A. Robertson, personal communication). This pole position is rather similar to those found previously for Prospect. Mt. Gibraltar and Gingenbullen and would suggest a Mesozoic age for the Ruby Hill intrusion. Preliminary results of a K-Ar age study of the Delegate intrusion (so similar petrologically to the Ruby Hill intrusion) have shown an age of about 170 ± 10 million years (Lovering, unpublished work) which is consistent with the palaeomagnetic data and strongly suggests that all these intrusions, including Ruby Hill, are lower Jurassic to upper Triassic in age and as such are considerably older than the established Tertiary flow basalts which occur over much the same area geographically.

The Deep-seated Inclusions

Both the breccia and basalt dykes at Ruby Hill contain xenoliths of granulitic, eclogitic and ultra-basic rocks which show considerable similarities with similar inclusions found in other breccia pipes in Eastern Australia (e.g. Delegate).

Card (1902) first described the occurrence in the Ruby Hill breccia of fragments of a rock consisting of garnet-plagioclase clino-pyroxene-kyanite which he called an " eclogite ". It is now generally agreed that feldspar is not a stable phase in rocks of the eclogitic facies, so that the rock described by Card is better described as a garnet granulite of the granulite facies. In the present study many garnet granulite inclusions were observed but a number of true eclogite inclusions (consisting entirely of garnet and jadeitic clino-pyroxene assemblages) were also found. Card (1902) also described an ultra-basic inclusion (containing olivine, pyroxene, amphibole and pleonaste) from the breccia but no unaltered ultra-basic inclusions were found during this study. Several extremely carbonated inclusions were found and may represent extremely altered ultra-basic inclusions.

Garnet granulite inclusions

The " eclogite " inclusions described by Card (1902) are better termed garnet granulites and are essentially coarse grained assemblages of garnet-clino-pyroxene-plagioclase. Scapolite is usually an important minor phase and had been identified as kyanite by Card (1902). Modal analyses on three garnet granulite inclusions (Table 4) are remarkably similar, while the analysis reported by Card (1902) agrees well with an analysis of a garnet granulite collected during the present study (Table 2). Card's analysis indicates nepheline in the molecular norm while the new analysis does not have free nepheline. However, both analyses indicate that the garnet granulites have affinities with undersaturated basic magmas.

The garnet grains are virtually all altered to a confused mixture of fibrous chloritic material, brownish-green hornblende and opaque minerals but occasionally some unaltered cores are found. Unaltered garnet grains also occur as inclusions within clino-pyroxene crystals. The refractive index of the garnet is 1·766 and is similar to garnets in garnet granulite and eclogite inclusions from the Delegate pipe (Lovering, unpublished work).

The clino-pyroxene is normally unaltered and coloured very pale shades of bluish and greenish-grey. Optical properties are very similar to those of the clino-pyroxene in the eclogite inclusion (Table 5) and the analysis reported by Card (1902) also would indicate that it is a jadeitic clino-pyroxene with strong similarities to those characteristic of eclogitic rocks (Table 6).

The plagioclase grains are virtually untwinned with well-developed cleavages. There is some secondary iron-stained chloritic and/or zeolitic material in fractures but on the whole the plagioclase grains are quite fresh. The refractive index $\beta = 1 \cdot 570 \pm 0 \cdot 002$ indicates that the plagioclase is labradorite-bytownite (71 mol. per cent An).

Rutile, often with opaque inclusions, is a minor accessory mineral and forms elongated brown crystals.

A very important minor phase is scapolite, which occurs as well developed euhedral grains about 0·5 mm. long or even larger. Cleavages

TABLE 4

Modal Analyses of Inclusions in the Ruby Hill Pipe

	Phases (volume per cent)	Garnet Granulites			Eclogites
		MM 1929C*	MM 1929E*	R 165†	R 169†
Primary Phases	Clino-pyroxene				
	Unaltered	27·2	25·8	26·8	34·5
	Altered	0·0	0·0	0·0	11·9
	Total	*27·2*	*25·8*	*26·8*	*46·4*
	Garnet				
	Unaltered	0·2	0·2	0·0	0·2
	Altered	35·9	45·2	38·4	49·4
	Total	*36·1*	*45·4*	*38·4*	*49·6*
	Plagioclase	*29·9*	*22·8*	*24·1*	—
	Scapolite				
	Unaltered	1·0	1·1	2·2	—
	Altered	5·8	4·9	2·5	—
	Total	*6·8*	*6·0*	*4·7*	—
	Rutile	—	—	*0·5*	*0·5*
Secondary Phases	Chlorite (interstitial)	—	—	5·5	0·5
	Plagioclase (interstitial)	—	—	—	1·9
	Magnetite (interstitial)	—	—	—	0·3
	Calcite (interstitial)	—	—	—	0·5

* Slide number in collection of the Mining Museum, N.S.W. Geological Survey.
† Specimen number in personal collection, Department of Geophysics, Australian National University.

are often well developed and each scapolite crystal normally has a distinct alteration zone around its margin. The alteration zone may be interrupted where the grain is in contact with clino-pyroxene and a few scapolite grains observed within clino-pyroxene grains were virtually unaltered. The alteration zone is most obvious when the scapolite is near an altered garnet grain. The alteration zone is made up of tiny plagioclase crystals, showing well developed fine twinning lamellae with high $2V_x$ and an average refractive index close to 1·570 indicating a composition close to An_{70}. The scapolitization of plagioclase is observed in many geological environments but the texture in this case indicates the reverse process—

TABLE 5

Optical Properties of Clino-pyroxenes from Garnet Granulite and Eclogite Inclusions

Optical Property	Clino-pyroxene from Garnet Granulite (R165)	Clino-pyroxene from Eclogite (R169)
Refractive indices*		
α	1·693	—
β	1·700	1·708
γ	1·721	—
Optic axial angle		
$2V_\gamma$ (calculated)	60·5°	—
$2V_\gamma$ (measured)	$59\pm1°$	$58\pm1°$
Dispersion	Strong and inclined ($\rho>\nu$)	Strong and inclined ($\rho>\nu$)

* Determinations $\pm0·001$.

TABLE 6

Analysis of Clino-pyroxene from Garnet Granulite Inclusion in Ruby Hill Breccia Pipe
(After Card, 1902)

		Structural Formula (calculated on the basis of 6 (O))			
SiO_2	45·92	Si	1·66	2·00	
Al_2O_3	12·03	Al	0·34		
Fe_2O_3	2·24				
FeO	1·73	Al	0·18	0·24	1·99
MgO	13·30	Fe^{3+}	0·06		
CaO	22·73				
Na_2O	1·19	Mg	0·72	0·77	
K_2O	0·32	Fe^{2+}	0·05		
H_2O+	0·66				
CO_2	0·39	Ca	0·88	0·98	
		Na	0·08		
Total	100·51	K	0·01		
D	3·338				

$Ca_{51·5}$ $Mg_{41·9}$ $Fe_{6·6}$

Analyst: H. P. White.

the alteration of scapolite to plagioclase. The refractive indices for the scapolite are $n_o=1\cdot588$, $n_e=1\cdot565$ ($d_n=0\cdot023$, $n_m=1\cdot576$) and suggest a composition of 80 mol. % Meionite using curves published by Shaw (1960). However, an analysis of a scapolite grain by the electron probe X-ray microanalyser shows that the halogen content is very low but that the sulphur content is extremely high (approximately 2·3% S). Shaw (1960) has shown that other sulphur-rich scapolites do not fit on his curve relating n_m and meionite content so that the scapolite in the Ruby Hill garnet granulites probably has a meionite content closer to 70 mol. % than to 80% (as determined from Shaw's curve). The lower meionite content would be consistent with the observation that the composition of the plagioclase in the alteration zone is about 70 mol. % An. The significance of the occurrence of sulphur-rich scapolites in the garnet granulite inclusions will be discussed elsewhere (Lovering and White, 1963).

Veins of zeolitic material occur within some of the garnet granulites.

The eclogitic inclusions

A number of inclusions were found consisting essentially of coarse grained garnet-clino-pyroxene assemblages with accessory rutile and a number of secondary phases resulting from the advanced alteration of the garnet grains (Table 4). Analysis of one such eclogite inclusion (Table 2) shows an overall similarity with the garnet granulite inclusions although the molecular norm contains a very small amount of quartz probably arising from the high oxidized iron content of the altered rock. It seems likely that in the unaltered state this eclogite would have had affinities with a saturated basic magma.

The garnet grains are virtually completely altered to a felted mass of brown chlorite and/or hornblende with opaque grains. A few very small cores of unaltered garnets were observed but sufficient material for the determination of optic properties was not available.

The clino-pyroxene is bluish or greenish grey, normally unaltered but with some recrystallization along grain boundaries. The optical properties are very similar to those clino-pyroxene in the garnet granulites (Table 5) and in eclogitic inclusions from the Delegate pipe (unpublished data). On the basis of this evidence it can be concluded that these clino-pyroxenes contain a significant proportion of the jadeitic molecule and are apparently true eclogitic facies pyroxenes. Some brown rutile grains occur as a minor phase in the eclogites and secondary veins and patches of chlorite, calcite, plagioclase and magnetite also occur.

The significance of the deep-seated inclusions

The co-existence of granulitic, eclogitic and ultra-basic inclusions in basic breccias and alkaline olivine basalts seems to be characteristic of certain igneous pipe-like intrusions of upper Triassic-lower Jurassic age over large areas of Eastern Australia. It is significant also that the diamond-bearing kimberlite pipes of South Africa (Williams, 1932) and Siberia (Bobrievich and Sobolev, 1957) also contain exactly comparable suites of inclusions which are generally considered to be of deep-seated origin (Lovering, 1958). In view of the similarity of the Australian inclusions with those from South Africa and Siberia, it is suggested that the Australian inclusions also represent fragments of possibly lower crustal and upper mantle materials caught up in the pipes during their intrusion into the upper parts of the earth's crust. In the light of evidence presented previously (Lovering, 1958) it is suggested that the granulitic inclusions probably represent material from the lower crust while the eclogitic and ultra-basic fragments represent material from the upper mantle. If this suggestion is correct it is of extreme importance to theories concerned with the nature and evolution of the earth's crust and upper mantle in that we have in these inclusions actual samples of both regions which can be studied directly in our laboratories.

Acknowledgements

The author is indebted to Dr. A. J. R. White for the measurements of the optical properties of the minerals quoted in this work and to A. J. Easton for the chemical analyses. Mr. D. R. Pinkstone, Mining Museum, Sydney, very kindly made available for study the original thin sections used by Card in his work on the inclusions in the Ruby Hill pipe. The author is indebted to Dr. J. F. G. Wilkinson for his comments on the original manuscript.

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On Traces of Native Iron at Port Macquarie, New South Wales

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Since the discovery of terrestrial iron on the west coast of Greenland in 1870, less than a dozen other in situ occurrences of the native metal have been reported. In Greenland and on the adjacent Disko Island, the iron is crystallized as a body-centred cubic phase, Alpha, [O_h^9 1m3m ; Z=2] (Berry and Thompson, 1962).

The native metal is also found crystallized in the Gamma face-centred cubic phase, [O_h^5 Fm3m ; Z=4]. γ irons studied up to the present time are nickel iron alloys. The following source localities have been reported : near Poschiavo, Switzerland (Quervain, 1945) ; Kärnten district, Austria (Ramdohr, 1950 ; Meixner, 1956) ; Corsica (Avias and Caillère, 1959) ; Tasmania (Ramdohr, 1950 ; Williams, 1960).

Small quantities of native iron have been found by the author in several rocks of a complex in the Port Macquarie district, an area lying north-east of Sydney, New South Wales, on the Pacific coast between latitudes 31° and 32°. The occurrence, which is regarded as petrologically significant, is unique because both α and γ phase irons are present and may even be found in one rock.

The native metal was first detected by extraneous lines in magnetite X-ray powder patterns. In order to confirm the discovery, any possible risk of iron contamination from outside sources was eliminated by resorting to Stone Age methods. During preparation of material for X-ray analysis specimens were broken and powdered by pounding with and between quartzite cobbles down to a stage where final grinding could be completed in an agate mortar.

The X-ray powder photographs illustrating this note are contact prints of films obtained in a Sträumanis type camera of 57·54 mm. diameter with cobalt Kα X-radiation (Fe filtered, λ=1·7902Å). Each photograph represents a separate extraction of opaque material from rock specimen No. 24333, University of Sydney, a quartz garnet glaucophane lawsonite assemblage, considered by the author to be a metamorphosed impure chert. Photograph A is the powder pattern of an α phase iron ; it shows lines indexed as 110, 200, 211 and 220 of a body-centred cubic lattice. The strongest lines of magnetite appear also and are indicated by their indices alongside the film strip. Contact print B shows the patterns of both α and γ irons superimposed. Measured *d* spacings, visually estimated intensities, Miller indices and calculated *a* parameters are listed in Table 1. The cell side for α iron of this film, 2·863Å, compares with 2·8665Å for pure iron (A.S.T.M. Index 1962) ; 2·863–2·877Å (Fe, Mn) (Donnay *et al.*, 1963) and 2·874Å for Disko Island terrestrial iron (Berry and Thompson, *ibid.*).

Table 1

X-Ray Powder Data for α and γ Irons of Specimen 24333, University of Sydney

B. α Iron			B. γ Iron			C. γ Iron (of Garnet)	
$d_{meas.}$ Å	$I_{est.}$	*hkl*	$d_{meas.}$ Å	$I_{est.}$	*hkl*	$d_{meas.}$ Å	$I_{est.}$
2·024	300	110	2·069	100	111	2·070	100
1·432	35	200	1·794	60	200	1·795	40
1·169	90	211	1·270	50	220	1·268	25
1·012	30	220	1·083	75	311	1·081	30
			1·038	15	222	1·034	10
a_0=2·863			a_0=3·591			a_0=3·584	

The γ iron of this photograph with lines indexed as 111, 200, 220, 311 and 222, has a cell side of 3·591Å.

The γ iron pattern is shown isolated in contact print C. In this case faint extraneous lines are due to reflections from the 420, 640 and 642 planes of garnet.

Data for this film are given in Table 1 also. The opaque inclusions from 0·02–0·05 mm. diameter garnets of specimen 24333 have produced this pattern of a γ iron. Native iron has not, so far as the author is aware, been recorded as an inclusion in garnet. The parameters for the irons of specimen 24333 differ slightly; that for the inclusions in the garnet host being 3·584Å. Both values compare with cell dimensions for nickel irons, the range of which is from 3·614Å (Fe_{50}, Ni_{50}) (Donnay *et al.*, *ibid.*); through 3·560Å, Josephenite (Berry and Thompson, *ibid.*); to 3·54Å, Awaruite (Williams, *ibid.*). But microchemical tests show that the associate of iron is not nickel but manganese. The field area specified is still under investigation by the author.

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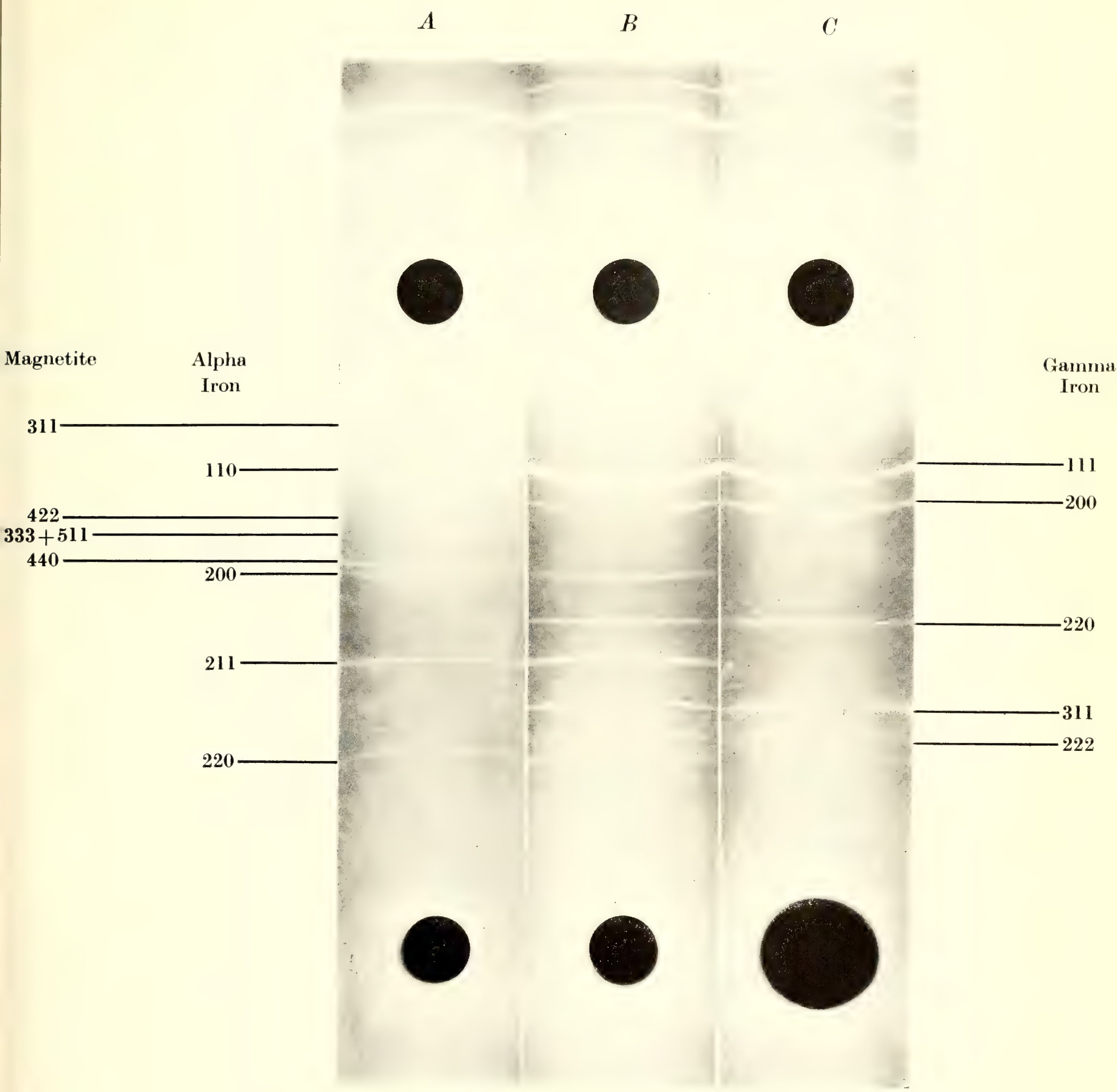
Explanation of Plate

X-ray powder patterns of three samples, each from specimen U.S.G.D. 24333.

A. Alpha iron associated with magnetite.
B. Alpha and gamma iron mixture.
C. Gamma iron extracted from garnets.


A
B
C
Magnetite
Alpha Iron
Gamma Iron
311
110
422
333+511
440
200
211
220
111
200
220
311
222

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LEPIDOPHLOIOS and CYRTOSPIRIFER from the Lambie Group at Mount Lambie, N.S.W.

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Abstract—*Lepidophloios* sp. indet., *Cyrtospirifer inermis* (Hall), *C. oleanensis* Greiner and *C. gneudnaensis* Glenister are recorded and figured, together with diagnoses and Australian references. The evidence for an Upper Devonian age for the Lambie Group is reviewed.

Lepidophloios

This to my knowledge is the first record of the occurrence of this genus in Eastern Australia. The single specimen was kindly given to me by Dr. J. Connolly, who found it in the upper reaches of Solitary Creek near Rydal.

Division. Lycopsida.

Genus. *Lepidophloios* Sternberg 1826.

Diagnosis. " *Lepidophloyos.* Caudex arboreus rudimentis petiolorum squamatus, cicatrice triglandulosa subsquamis." Sternberg.

Translation (with the assistance of Mr. A. M. Brough) : The stem of a tree with scale-like leaf cushions and primitive petioles. Small leaf scars on the leaf cushion bear three round pits.

Discussion. The change of name of Sternberg's *Lepidophloyos* to *Lepidophloios* apparently occurred pre-1893 and is probably only a correction of the original Latin. Kidston (1893) discusses fully the relation of *Lomatophloios*, *Halonia*, *Pachyphloeus* and *Cyclocladia* to *Lepidophloios* and concludes that they " . . . merely represent different conditions of growth and preservation of one generic type ". Of the relation of *Lepidophloios* to *Lepidodendron* Seward (1910, p. 105) says : " . . . apart from the form of the leaf cushion . . . we are at present unable to recognize any well defined differences between the two forms *Lepidodendron* and *Lepidophloios*. The leaf cushions of *Lepidophloios* differ from those of the true *Lepidodendron* in their relatively greater lateral extension, in their imbricate arrangement and in bearing the leaf, or leaf scar at the summit."

The specimen of *Lepidophloios* described here does not exhibit any characteristics (branching, etc.) by which its correct orientation can be determined. Since the leaf cushions may be directed upward or downward in different species, or vary in orientation within a single specimen of some species (see Kidston, 1893, pp. 544 and 552 for discussion), this structure cannot be used for orienting purposes. The specimen is arbitrarily oriented with the leaf cushions directed upward and the leaf scar at the top of the cushion.

Lepidophloios sp. indet.

Plate I, Fig. 12

Material. U.S.G.D.* Specimen N° 7016.

Locality. Wallerawang 1:63,360 military sheet ref. 001650.

Horizon. 2,200 feet above the unconformable base of the Lambie Group (refer Mackay, 1961).

Description. Specimen N° 7016 is an impression of a piece of bark, 2·8 cm. wide and 8·5 cm. long, preserved in fine quartzose sandstone. The surface is completely covered by rhomboidal, horizontally elongate, convex leaf cushion impressions, 11 mm. wide and 7 mm. long. The latter have acute lateral and upper angles but rounded lower angle and bear, at their summits, triangular leaf scars. The fine markings on the leaf scar are not preserved and hence a specific identification cannot be made.

Cyrtospirifer

The material described, which was collected from two localities near Rydal in the same stratigraphic horizon, is listed in Table I.

The brachiopods are preserved as internal and external molds in fine quartzose sandstone. The shell material, where not completely removed, has been replaced by a pink well-crystallized kaolinite.

Systematic Descriptions

Family. Spiriferidae King 1846.

Genus. *Cyrtospirifer* Nalivkin in Fredericks, 1926.

Diagnosis. Medium sized plicate shells. Intercalation and bifurcation of the plications on the sulcus and fold, but never on the lateral

* All specimen numbers refer to the University of Sydney Geology Department, Palaeontology Collection.

TABLE 1

Species	U.S.G.D. Specimen Nos.	
	Locality A	Locality B
Cyrtospirifer inermis	1355 8, 1355 9, 13580	13550 A–F, 13551 A–D 13554 A–B, 13555 B–C 13556 A–C, 13557 A–C 13561 A–F, 13564 A–B 13568 A–C, 13569 A–C 13570 A, 13571 A–D 13572 A, 13574 A–B 13575, 13579 13581
C. oleanensis	13552 A–C, 13562 13563, 13565 A–C, 13566 A	13555 A
C. gneudnaensis	13560	

Locality A. Wallerawang 1 : 63,360 military map, grid ref. 001650.
Locality B. Bathurst 1 : 63,360 military map, grid ref. 973630.

slopes. Dental lamellae well developed, extending along the valve floor for one-third or more of its length, and joined posteriorly by a delthyrial plate or apical callosity. (Compiled from the literature.)

DISCUSSION. Since the erection of the subgenus *Cyrtospirifer* by Nalivkin in 1926, various attempts have been made to erect further genera or subgenera, especially by Grabau 1931 *et seq.* At present *Cyrtospirifer* is accorded generic status and the other proposed subdivisions, with the exception of *Cyrtiopsis*, have been generally rejected. I am not in a position to express a personal opinion on the status of *Cyrtiopsis* but it appears that the validity of this genus is at present not established and those authors who support its retention do not agree on diagnostic generic characters.

The original author, Grabau (1923, 1931–33) states that *Cyrtiopsis* is similar to the " Upper Devonian *Spirifers* " and differs from them " only in the persistence of the pseudo-deltidium which moreover is pierced ". Paeckelmann (1931) and Sartenaer (1956) also believe that the presence or absence of a deltidium constitutes the distinction between *Cyrtiopsis* and *Cyrtospirifer* respectively. But, as Vandercammen (1959) points out, this apparatus can readily be lost before preservation and Glenister (1955) agrees " that absence in the fossil state of apparatus for closing the delthyrium does not constitute proof that this apparatus did not exist ". Glenister however states that *Cyrtiopsis* has " . . . long convergent curved dental lamellae " whilst *Cyrtospirifer* has " . . . shorter divergent lamellae ". To further support his claim of generic status for *Cyrtiopsis* he states " . . . Crickmay at least has shown that in North America the genus *Cyrtospirifer* is restricted to Frasnian equivalents, while *Cyrtiopsis* is restricted to Famennian equivalents ". This last piece of supporting evidence rests solely on the validity of Crickmay's faunal division. In his paper (1952) Crickmay gives no generic diagnoses but states (p. 587) : " The resemblance of such forms as *Cyrtiopsis kindlei* to *Cyrtospirifer* is external and megascopic only. The long, thin, curved, sub-parallel dental lamellae of *C. kindlei* are typical of *Cyrtiopsis* and are very different from the short, straight, divergent lamellae of *Cyrtospirifer*. There are also notable differences in apical and umbonal callus, and in manner of ornament and micro-ornament." From his descriptions of species it appears that *Cyrtiopsis* is characterized by dental lamellae of length 45%–55% of the length of the valve, and micro-ornament consisting generally of concentric microfila and radial micro-striae and completely lacking pustules. *Cyrtospirifer* on the other hand has dental lamellae of length 30% to " 35% or more " of the length of the valve and micro-ornament generally consisting of concentric microfila with pustules developed on the plications, though pustules may be absent and faint radial micro-striae may be present.

Application of this basis of distinction between the two genera to the 13 sufficiently well preserved species of *Cyrtospirifer* described by Vandercammen (1959) yields five species, *C. stolbovi*, *C. tenticulum*, *C, bisinus*, *C. syringothyriformis* and *C. conoideus* which fit into Crickmay's genus *Cyrtospirifer* ; *C. canaliformis* and possibly *C. monticolaformis* which fit into his genus *Cyrtiopsis* ; one species *C. orbelianus*, which combines dental lamellae of length up to 50% of the valve with pustules in the micro-ornament ; and three species *C. brodi*, *C. verneuili* and *C. grabaui*, which have the short, divergent dental lamellae typical of Crickmay's genus *Cyrtospirifer* together with micro-ornament — concentric microfila plus radial micros-striae and completely lacking pustules— typical of Crickmay's genus *Cyrtiopsis*. Greiner's (1957) and Glenister's (1955) descriptions of micro-ornament are not sufficiently detailed to allow comparison of their species. The degree to which Crickmay's distinguishing features can be applied to Vandercammen's species does not indicate that they will be generally applicable, and hence it is questionable whether his generic distinctions and resulting faunal division are valid. This literature survey reveals that at

present *Cyrtiopsis* does not stand as a clearly defined genus separated from *Cyrtospirifer.* Intensive study of the holotype of *Cyrtiopsis* and the large group of species of *Cyrtospirifer* must be carried out to justify the erection of a separate genus and provide a basis for its definition. For this reason *Cyrtiopsis* is subsequently ignored.

Recent work on *Cyrtospirifer* has resulted in the erection of a large number of new species, and each author has stressed different characters as the most important for distinguishing species. Grabau (1931–33) virtually ignores internal structures; Crickmay (1952), Vandercammen (1959) and Paeckelmann (1942) describe both externals and internals, but Crickmay and Vandercammen use only external characters, and Paeckelmann uses mainly external characters for distinguishing between species. It should be noted here also that Vandercammen and Paeckelmann do not consider the nature of the plications—bifurcating on the fold and sinus and simple on the flanks—a diagnostic generic character. In fact Vandercammen describes one species *Cyrtospirifer utahensis* (Meek, 1876) which shows bifurcation of plications over the entire shell.

Glenister (1955) stresses the use of as many characters as possible for intraspecific discrimination, but again uses only externals for his comparisons between species. In his intensive study of that group of American species formerly lumped together under the name of "*Spirifer disjunctus*", Greiner (1957) has carefully described both internals and externals of 16 species of *Cyrtospirifer* and his intraspecific distinctions include several of both groups ot structures. As my material, which was also described by early authors as "*S. disjuncta*", exhibits well preserved internals and only moderately preserved externals I have found Greiner's work the most useful and have relied more heavily upon it than upon the work of any other author.

Cyrtospirifer inermis (Hall) 1843
Plate I, Figs. 1–5

Synonymy as in Greiner (1957).

In addition the following Australian references.

1876. *Spirifer disjunctus* Sowerby. de Koninck pp. 79–81.

1880. *Spirifer disjuncta* Sowerby. Etheridge Jnr., p. 255, Pl. Fig. 5.

1951. *Cyrtospirifer subdisjunctus.* Maxwell. Maxwell, p. 8, Pl. 1, fig. 17 (*a–c*).

Diagnosis. Shell wider than long, sulcus and fold well defined; dental lamellae vertical and divergent anteriorly; ventral muscle field longitudinally striate and bisected by a spear-shaped median septum; dorsal muscle field not prominent, dorsal median septum slender.

Description. Shell biconvex, ventral valve the more strongly curved; width about twice the length, hinge line produced to form small angular ears. Valves ornamented with radiating plications, simple on the flanks but intercalated on the fold and sulcus; faint concentric growth lines sometimes visible.

Convexity of pedicle valve interrupted by narrow sulcus originating at beak and bounded by prominent plications; beak slightly overhangs a prominent, oblique-angled triangular interarea (sensu Cloud, 1942, p. 13), which bears faint longitudinal striations. Interarea orthocline* and flat, rarely slightly concave, except at the posterior extremity, where it is gently anacline. Delthyrium high triangular, delthyrial angle 26° to 52°, 42°–44° being the most common values. A narrow, sharply depressed shelf bordering the delthyrium (Fig. 3) indicates the former presence of a deltidium (sensu Cloud, 1942), exact nature of deltidium unknown. Internally strong, vertical divergent dental lamellae extend anteriorly along the valve floor for one-third to one-half its length. The dental lamellae thicken, or are secondarily thickened posteriorly and are joined along their posterior half by a delthyrial plate which rapidly develops posteriorly into an apical callosity; from the base of the latter a prominent spear-shaped median septum extends anteriorly for one-third the distance to the anterior margin. A few striations paralleling the median septum mark the muscle field.

The fold on the dorsal valve is sharply elevated above the flanks; the beak slightly overhangs a low dorsal interarea, which is bisected by a small triangular notothyrium. Internally only a very thin median septum, extending along the valve floor for about one-third the valve length, is visible.

Cyrtospirifer oleanensis Greiner 1957
Plate I, Figs. 6–9

Synonymy as in Greiner 1957.

In addition the following Australian reference.

1951. *Sinospirifer sinensis* Grabau var. *australis* Maxwell. Maxwell, p. 6, Pl. 1, Fig. 9*a*, *b*; Pl. 2, Fig. 3.

Diagnosis. Shell almost semi-circular with ill-defined fold and sulcus; ventral muscle

* Nomenclature for the attitude of the interarea is that of Schuchert and Cooper (1932).

field circular, deeply imbedded, longitudinally striate anteriorly but radially striate posteriorly; dorsal muscle field large; median septa well developed.

Description. Shell biconvex, approximately semi-circular in outline, ventral valve the more strongly curved with maximum curvature in the vicinity of the umbo. Both valves ornamented with broad, flat-topped, radiating plications simple on the flanks but intercalated on fold and sulcus; faint concentric growth lines sometimes visible.

The ventral valve bears a shallow sulcus, originating at the beak and widening progressively anteriorly. The longitudinally striate, subrectangular uniformly concave interarea, which varies from gently apsacline to gently anacline, is bisected by an equilateral triangular delthyrium. On the internal mold a definite gap between the filling of the delthyrial cavity and the impression of the interarea indicates the former presence of a deltidium, whose exact nature is unknown. Internally the dental lamellae which are curved in section, follow a curving path along the valve floor for one-third of its length, bordering a deeply-imbedded circular muscle field. Anteriorly the dental lamellae consist only of low ridges but posteriorly are better developed and are joined by an apical callosity. From the base of the latter a short, rapidly-thinning median septum extends anteriorly for approximately one-quarter the diameter of the muscle field. The latter is radially striate posteriorly, longitudinally striate anteriorly.

Dorsal valve has a low fold and a low orthocline interarea bisected by a small triangular notothyrium. Internally, short longitudinal ridges locate the muscle field, which is bisected by a thin median ridge extending anteriorly for half the length of the valve floor.

Remarks. Greiner (1957) describes the ventral interarea of his species as " . . . curved, and narrowing rapidly towards the extremities ". The specimens described here have a more sub-rectangular ventral interarea, however the strong correspondence of all other characters justifies the identification of these specimens with Greiner's species.

Cyrtospirifer gneudnaensis Glenister 1955
Plate I, Figs. 10, 11

1955. *C. gneudnaensis* Glenister, p. 66, Pl. 5, figs. 6–27; Pl. 6, figs. 1–20.

Diagnosis. Shell unequally biconvex, approximately as wide as long, fold and sulcus weakly developed, ventral interarea low; dental lamellae low and relatively short; ventral muscle field oval, divided posteriorly for one-third its length by a prominent median septum. (Abstracted from Glenister's description.)

Description. Ventral valve semi-elliptical, strongly convex; sulcus shallow; exterior ornamented with fine radiating plications. Interarea sub-rectangular, flat and apsacline at the lateral extremities but gently concave, apsacline to anacline, medianly. Delthyrium large, delthyrial angle=60°. On the internal mold a definite gap between the filling of the delthyrial cavity and the impression of the interarea indicates the former presence of a deltidium. Exact nature of the latter unknown.

Internally curved dental lamellae extend along the valve floor for one-third its length, thickening, or secondarily thickened, posteriorly and joined just beneath the beak by a small apical callosity. From the base of the latter a short median septum of uniform width and height extends anteriorly for one-third of the distance across the muscle field. A broad median groove for the adductor muscle, confined between two very thin, sub-parallel ridges, completes the bisection of the muscle field. Very fine longitudinal striae are the only other features visible in the muscle field.

Remarks. Since only one well-preserved ventral valve was found, precise identification is difficult. There are some minor differences between this specimen and Glenister's specimens of *Cyrtospirifer gneudnaensis*, namely the sub-rectangular rather than triangular interarea, and the equilateral rather than broad low delthyrium. However, the striking correspondence of important internal structures leads me to place this specimen in Glenister's species.

Age of the Lambie Group

Since de Koninck's (1876) identification of the European Upper Devonian species *Spirifer disjunctus* and *Rynchonella pleurodon* collected from the Lambie Group at Walkers Point (presumably Mt. Walker), near Rydal, an Upper Devonian age for these rocks has not been seriously questioned. The additional discovery by David and Pittman (1893) of *Lepidodendron australe* near Mt. Lambie was taken to indicate an extension of the range of that species formerly considered by McCoy to be Carboniferous. In the intervening years *Spirifer disjunctus* or *Cyrtospirifer disjunctus*, *R. pleurodon* and *L. australe* have come to be regarded as hallmarks of the Upper Devonian, so that now wherever one or more of these species are identified an Upper Devonian age is immediately

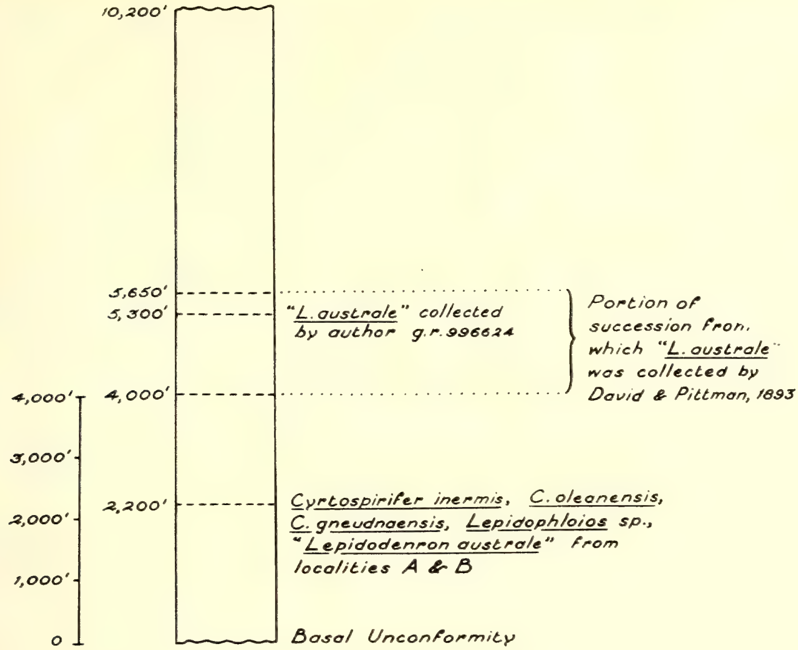

Fig. 1

assumed for the enclosing rocks. Excluding the New England province, such correlations as have been made in the " Upper Devonian " of New South Wales are based on spot determinations of species whose ranges in Australia are as yet unknown. Moreover, the validity of an Upper Devonian age for the rocks at Mt. Lambie, which has come to be considered the type area (Brown, 1931) depends completely on interregional correlation with Europe using two brachiopod species.

Exactly what palaeontological information do we have concerning the Lambie Group? The data so far available are presented in Figure 1.

The range of *Cyrtospirifer* in Australia is not yet known. In the Catskill delta, extending through New York, Pennsylvania and Ohio States, *Cyrtospirifer* ranges from the base of the Chemung (see Fig. 2) through the remainder of the Upper Devonian and into the basal beds of the Mississippian system (Greiner 1957). In Europe it ranges from the top of the Middle Devonian right through the Upper Devonian and into the lowermost beds of the Carboniferous (Vandercammen, 1959; Paeckelmann, 1942). A similar range in Australia is therefore very probable.

In the Catskill delta *C. inermis* ranges from Middle Chemung to lower Conewango and possibly into the uppermost Conewango; *C. oleanensis* ranges from Upper Conewango to Middle Cussewago (basal Mississippian) (Greiner, 1957).

Glenister (1955) suggests a late Frasnian age for *C. gneudnaensis* apparently solely on the basis of Crickmay's (1952) faunal division of the Upper Devonian section in North America the validity of which has already been questioned. Consequently little weight can be placed on Glenister's range for *Cyrtospirifer gneudnaensis*.

The range of *Lepidophloios* in Australia is quite unknown. In Europe Renier (1910), Kidston (1892), Seward (1910) and Arnold (1947) all state it to be a Carboniferous genus.

Finally, the stratigraphic value of *Lepidodendron australe* requires some discussion. Crook (1960) advocates a change of name to *Leptophloeum australe* but gives no reasons for such a change. Fischer (1904), in his review of the nomenclature of *Lepidodendron* and its species, deals with the relationship of *Lepidodendron australe* McCoy, *Lepidodendron nothum* Unger, which the former resembles, and *Leptophloeum rhombicum* Dawson to the genus *Lepidodendron*. He concludes that the holotype for each of these " species " is only imperfectly preserved or, more precisely, is in a *Bergerian* state of preservation, the epidermis having been lost or destroyed before fossilization. In this state

	CATSKILL DELTA	EUROPE
CARBONIFEROUS SYSTEM	Cussewago Stage	Tournaisian Stage
DEVONIAN SYSTEM	Conewango Stage	Famennian Stage
	Conneaut Stage	
	Cannadaway Stage	
	Chemung Stage	Frasnian Stage
	Fingerlakian Stage	

FIG. 2

Correlation of the Upper Devonian-Lower Carboniferous Zones of the Catskill Delta and Europe. (Compiled from data from Greiner (1957) and Wells (1956).)

all that remains is a vague outline of the leaf cushion and a " leaf scar ". This condition is shown by specimens of both *Lepidodendron* and *Lepidophloios* where the " leaf scar " represents the transverse section of the vascular bundle and the leaf-trace respectively. Such specimens cannot generally be assigned to a particular genus and certainly cannot be used for the erection of new genera. The position of the " leaf scar ", which was used by Dawson (1862) as a feature distinguishing his specimen from *Lepidodendron nothum,* varies according to the depth of removal of the epidermis and hence is of no generic or specific value.

Consequently specimens of the so-called " *Lepidodendron australe* " may be imperfectly preserved specimens of either *Lepidodendron* or or *Lepidophloios.* Seward 1910, p. 104, fig. 146 A and B, shows a specimen of *Lepidophlois* a portion of which exhibits *Bergerian* preservation. This portion is identical to the specimens from Mt. Lambie figured by David and Pittman (1893) as *Lepidodendron australe* and to other specimens collected by the writer from the same area.

Reviewing the available evidence, it is clear that a definite time span cannot be assigned to the time of deposition of the Lambie Group. An Upper Devonian age is probable but not confirmed. There is the complication of the occurrence low in the succession of a plant of possible Carboniferous age. It is unlikely that the solution to the problems of " Upper Devonian " stratigraphy will be found in the Mt. Lambie area. The succession is bounded above and below by unconformities (Mackay, 1961), the plant fossils are sparse, the brachiopods are abundant but virtually limited to a single horizon, and the upper four thousand odd feet are apparently unfossiliferous.

Other sections may prove more rewarding, particularly the Catombal Group which contains *Cyrtospirifer,* " *L. australe* ", *Bothriolepis*-type fishplates (Sussmilch, 1906), and, in the uppermost beds, *Rhacopteris*-type plant remains (Stevens, 1950). It is in more continuously and richly fossiliferous sections that the basis for " Upper Devonian " stratigraphical palaeontology must be sought.

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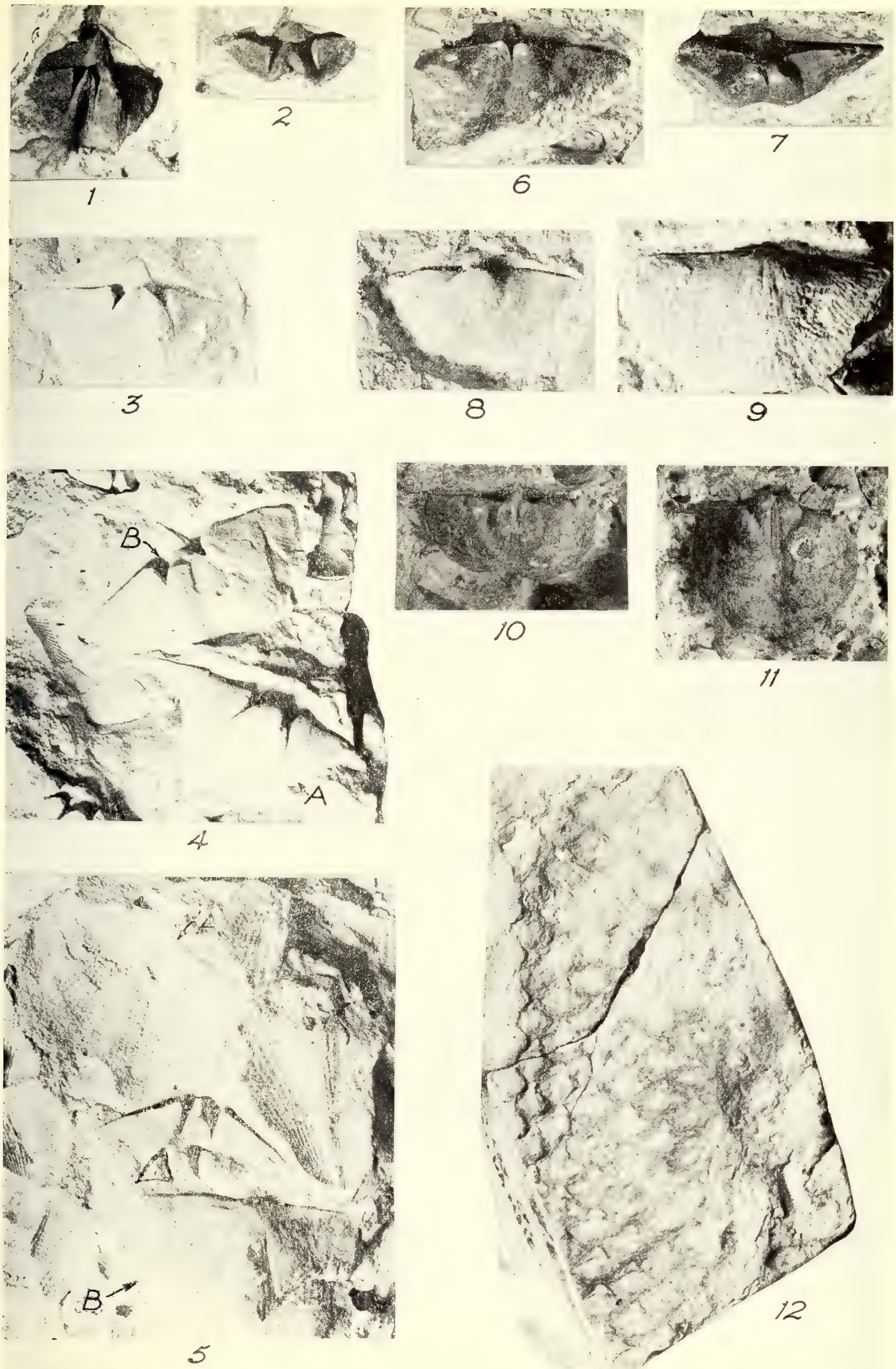
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Explanation of Plate I

All figures are reproduced at natural size

Fig. 1. *Cyrtospirifer inermis*. U.S.G.D. N° 13,558. Internal mold of pedicle valve, ventral view.
Fig. 2. Same as Fig. 1, posterior view.
Fig. 3. *C. inermis*. U.S.G.D. N° 13,570. A. Internal mold of pedicle valve.
Fig. 4. *C. inermis*. U.S.G.D. N° 13,564. A and B. Internal molds of pedicle valves.
Fig. 5. *C. inermis*. U.S.G.D. N° 13,550. A. External mold of pedicle valve. B. Internal mold of brachial valve.
Fig. 6. *C. oleanensis*. U.S.G.D. N° 13,563. Internal mold of pedicle valve, ventral view.
Fig. 7. Same as Fig. 6, posterior view.
Fig. 8. *C. oleanensis*. U.S.G.D. N° 13,565. Internal mold of pedicle valve.
Fig. 9. *C. oleanensis*. U.S.G.D. N° 13,562. Internal mold of brachial valve.
Fig. 10. *C. gneudnaensis*. U.S.G.D. N° 13,560. Internal mold of pedicle valve, ventral view.
Fig. 11. Same as Fig. 10, posterior view.
Fig. 12. *Lepidophloios* sp. indet. U.S.G.D. N° 7016.

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Devonian Trilobites from the Wellington-Molong District of New South Wales

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Abstract—A small collection of trilobites from the Lower to Middle Devonian Garra Formation is described, including the new species *Otarion munroei* and *Crotalocephalus packhami*. The fauna shows a strong resemblance to those already known from the Upper Silurian and Lower Devonian of south-east Australia, and it is suggested that these faunas have evolved slowly.

Introduction

Trilobites have not previously been described from the Garra Beds, a formation of Lower to Middle Devonian limestones and shales outcropping in a 60-mile belt passing through Cudal, Molong and Wellington, N.S.W. A collection of several thousand specimens made in the course of detailed field-work contains only about 50 specimens of trilobites, most of which are fragmentary. The following forms have been identified, or are herein named :

- *Scutellum* (*Scutellum*), sp. indet.
- *Otarion munroei*, sp. nov.
- *Cheirurus* (*Crotalocephalus*) *packhami*, sp. nov.
- *Gravicalymene australis* (Etheridge and Mitchell, 1917).
- *Calymene*, sp. nov. ?
- *Leonaspis*, sp. indet.

Stratigraphy : Following reconnaissance mapping by Joplin and Culey (1938) and by Basnett and Colditz (1946), and studies of the corals by Hill and Jones (1940), Hill (1942) and Jones (1944), it was thought that the Garra Beds could be divided, both lithologically and palaeontologically, into a lower series of shales, and an upper series of limestones. Detailed mapping by the author has shown that, while this subdivision remains broadly tenable, facies changes are frequent and rapid. Insufficient outcrop, coupled with these lateral and vertical changes, prevent consistent stratigraphic subdivision of the Garra Beds.

Shales and calcareous shales occur throughout the sequence, but are commonest towards the base of the formation. Here, the fauna is generally poor, dominated by the corals " *Cystiphyllum* " sp. Hill and Jones, *Tryplasma columnare* Etheridge fil., and (locally) *Radiophyllum arborescens* Hill and Jones. Common brachiopods are *Atrypa* sp. cf. *reticularis* (Linné)—which extends throughout the formation—and *Schellwienella* sp. nov. Hill (1942) distinguished this fauna from the " Murrumbidgee " fauna near Wellington, and, mainly on the basis of the favositids and *Tryplasma*, assigned it to the Coblenzian Stage. However, the corals—except perhaps for *Radiophyllum arborescens* — are found throughout the succession. Moreover, Philip (1960*b*) has shown the difficulty of using favositids without very detailed study. Consequently the age of the lower part of the Garra Formation must for the present remain uncertain. Hill's (1942) " Murrumbidgee " fauna, occurring in the more richly developed limestones towards the top of the formation, closely resembles the Sulcor-Loomberah fauna of Tamworth, and the Buchan Caves limestone of Victoria, which is known to be equivalent to the Couvinian in age (see Philip, 1960*a*). As the trilobites here described are from the lower strata, mostly the shales, they must be no younger than this. They show some affinity with previously described Upper Silurian and basal Devonian species, but are at present of doubtful use in age determination.

In the following systematic section, the terminology and classification in Moore (1959—Treatise on Invertebrate Paleontology, Part O) are used without modification. Specimens are housed in the palaeontological collection of the Department of Geology and Geophysics, University of Sydney.

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Systematic Palaeontology

Family THYSANOPELTIDAE Hawle and Corda, 1847

Scutellum (*Scutellum*) Pusch, 1833

Type species : *Scutellum costatum* Pusch, 1833. Givetian, Iserlohn, Germany.

Remarks : Several species have been described from Australia under the names *Bronteus* Goldfuss and *Goldius* de Koninck (junior synonyms of *Scutellum* Pusch).

Scutellum (*Scutellum*), sp. indet.

Plate I, Fig. 1

Material : Two incomplete pygidia, SU 6932 ; from road, at junction of portions 81, 104 and 105, parish of Brymedura, county Ashburnham.

Description : The pygidia are semi-elliptical, almost flat, with a small, transverse, triangular axis which is bounded anteriorly by a very narrow straight articulating half-ring. The median lobe is slightly raised, wider posteriorly than anteriorly. Each pleural field bears seven radially arranged flat ribs, separated by narrow, shallow furrows. The median rib is wide and undivided, its sides diverging gradually posteriorly ; its forward end expands slightly to meet the median lobe. The forward ends of the two ribs on each side of the median rib are curved gently forward, to meet the median lobe tangentially. The ribs and axis are finely tuberculate.

Comparison : Of the species described by Etheridge Jr. and Mitchell (1917), two are from " Molong, Parish Bell, . . . limestone-beds adjacent to Molong ". Ordovician and Silurian limestones outcrop in Molong itself, and Devonian limestones of the Garra Beds are not far to the west, still in Bell parish. Of the two species, *S. mesembrinus* (Etheridge fil. and Mitchell) is tuberculate, but without a distinctly trilobed pygidial axis ; moreover, the lateral ribs are strongly rounded. The Garra pygidia resemble those of *S. bowningensis* (Etheridge fil. and Mitchell, 1917) in outline. Although not visible in the figures, there is " . . . faint evidence of sparse granulation, . . . " on the pygidium of this species.

S. cresswelli (Chapman, 1915) is poorly figured, and cannot accurately be compared with the Garra specimens. *Goldius greeni* Chapman, 1915, is not a *Scutellum*. The mushroom-shaped glabella with three small lateral furrows, and the flat pygidium whose ribs bear fine transverse ridges, suggest *Eobronteus* Reed, 1928 (see Šnajdr, 1960, p. 245). This genus does not, however, possess the distinctly trilobed axis and strongly bifurcating median rib of the Victorian species. Chapman's two species are the only Devonian ones from Eastern Australia known to me.

Family OTARIONIDAE Richter and Richter, 1926

Subfamily OTARIONINAE Richter and Richter, 1926

Otarion Zenker, 1833

Type species : *Otarion diffractum* Zenker, 1833.

Remarks : Most species have been described under the junior synonym *Cyphaspis* Burmeister. The genus is known from the Middle Silurian to the basal Devonian of Eastern Australia.

Otarion munroei, sp. nov.

Plate I, figs. 2*a–c* ; text-fig. 1

Holotype : SU 6934 (cephalon only) ; from gully, por. 45, ph. Catombal, co. Gordon, 30 yds. east of por. 38.

Paratypes : SU 6935 to 6937 ; same locality.

Etymology : The species is named after Mr. G. Munroe, on whose property (" Catombal ") it was found, in appreciation foı his hospitality.

Diagnosis : Small *Otarion* with highly convex cephalon ; glabella separated from convex, steeply sloping pre-glabellar field by narrow furrow ; eyes large, dome-shaped ; genal spines short.

Description—Cephalon : The cephalon is small, semi-circular, and strongly convex. The glabella is broadly rounded anteriorly, with gently curved sides diverging slightly posteriorly. The occipital ring is narrow, but strong ; the occipital furrow is straight, deep and narrow (*sag.*). The *1p* lateral glabellar furrows are fine, slanting sharply back to separate the small narrow triangular *1p* lobes from the glabella proper. The axial furrows are deep and narrow, sharply separating the glabella from the small fixigenae. The axial furrows are truncated anteriorly by the narrow pre-glabellar furrow, whose shallow abaxial ends extend beyond the axial furrows, to die out at the facial sutures. The pre-glabellar field is convex, wide (*sag.*), and slopes steeply down to the border furrow. The border is convex, thick, and smooth. The facial sutures diverge rearwards across the border and border furrow, then converge to the bases of the eyes ; a small palpebral lobe extends towards the top of each eye. Behind the eyes, the sutures diverge gently to the posterior margin.

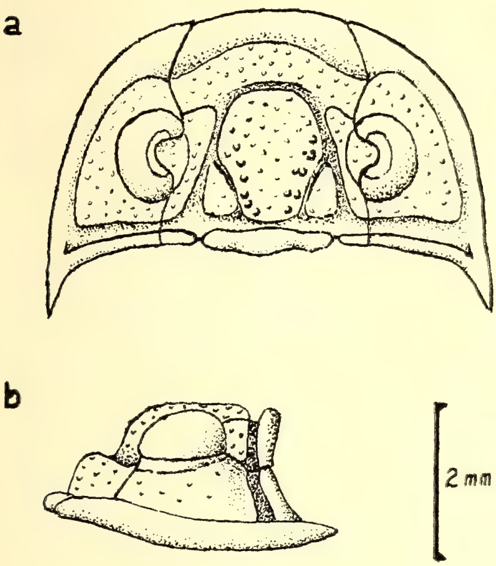

FIG. 1

Cephalon of *Otarion munroei* sp. nov., reconstructed from holotype and paratypes : dorsal (*a*) and side (*b*) views ×10.

The librigenae are large, sloping steeply up from the narrow border furrows, and are surmounted by large dome-like, subcircular to crescentic eyes. The lateral and posterior borders project rearwards as short, sharp genal spines.

Surface sculpture is granulose, typical of the genus. The largest granules are in two short rows on the glabella, just adaxial to the *1p* furrows.

Thorax, pygidium : Unknown.

COMPARISON : *O. munroei* is quite unlike the species of Etheridge Jr. and Mitchell (1893), having much larger eyes and librigenae, and short genal spines. *O. lilydalensis* (Chapman, 1915) is closer. In this species, the pre-glabellar field is neither as prominent nor as steeply inclined as in *O. munroei*, which differs also in that the posterior portions of the facial sutures are not widely divergent. The large eyes distinguish *O. munroei* from all the foreign species that I have seen figured.

Family CHEIRURIDAE Salter, 1864

Subfamily CHEIRURINAE Salter, 1864

Cheirurus (*Crotalocephalus*) Salter, 1853

TYPE SPECIES : *Calymene articulata* Münster, 1840.

Cheirurus (*Crotalocephalus*) *packhami*, sp. nov.

Plate I, fig. 7 ; text-fig. 2

1917. *Crotalocephalus sculptus* Etheridge fil. and Mitchell, Pl. XXVI, fig. 11, *only*.

HOLOTYPE : SU 6901. The Sydney University Palaeontology Catalogue gives the location as " Bank of Nora Ck., 300 yds. W. of road. The Gap, por. 191." This is inaccurate, the exact locality being an outcrop on the north bank of the creek, 700 yards north-east of the road crossing ; SE corner, por. 191, ph. The Gap (personal communication Dr. G. H. Packham).

ETYMOLOGY : The species is named after the collector, Dr. G. H. Packham.

DIAGNOSIS : Glabella parallel-sided, with bulbous frontal lobe ; trans-glabellar furrows gently V-shaped, shallow axially. Fixigenae small, faintly pitted ; genal spines very short.

DESCRIPTION—Cranidium : The glabella is large, parallel-sided to slightly convergent posteriorly, the greatest width being over the posterior part of the frontal lobe. The occipital ring is thick, the occipital furrow narrow, joined axially by the wide, strongly V-shaped pre-occipital glabellar furrow. The pre-occipital glabellar lobes are small, triangular. The *2p* and *3p* furrows are very broadly V-shaped, and relatively shallow axially. The frontal lobe is semicircular, bulbous, and slightly overhangs the narrow anterior border. The axial furrows are deep, straight and narrow. The faintly pitted fixigenae are small, each forming nearly a

Cephalic Dimensions, Otarion munroei

Specimen No.	Length		Height	Width	Glabella	
	Sagittal	Overall			Length	Width
SU 6934	3·2	3·9	2·0	5·8	1·7	1·8
6935	3·7	4·5+	2·0	6·8	2·1	1·7
6936	3·2	3·8+	1·7	c. 4·6	1·7	1·3
6937	3·2	3·5+	1·9	5·0	1·5	1·4

All measurements are in mm.

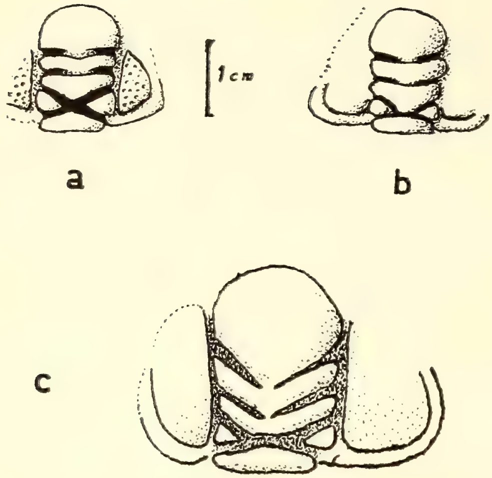

Fig. 2

(*a*) Cephalon of *Crotalocephalus packhami* sp. nov.; traced from photograph of holotype, ×1; (*b*) cephalon of *C. sculptus* Etheridge fil. and Mitchell, 1917, pl. XXVI, fig. 11 *only* (=*C. packhami*); traced from published photograph; (*c*) cephalon of *C. sculptus*; traced from pl. XXV, fig. 8, of Etheridge Jr. and Mitchell, 1917. Scales of (*b*) and (*c*) not given in original publication.

quadrant of a circle. The eyes are small, close to and opposite the *3p* lobes; the facial sutures run directly forward and outward from them, to enclose 90°. The fixigenae, which are narrower than the occipital ring, slope rather strongly down to the flat or gently concave border; there is a pair of short genal spines.

Librigenae, thorax and pygidium: Unknown.

Comparison: The cephalon figured by Etheridge Jr. and Mitchell (1917, Pl. 26, fig. 11) as *Crotalocephalus sculptus* agrees exactly with the holotype of *C. packhami*. Both are quite distinct from *C. sculptus* S.S., which is characterized by deeply V-shaped trans-glabellar furrows. Etheridge Jr. and Mitchell did not give a locality for their specimen, nor were a number and repository listed. In *C. silverdalensis* Etheridge Jr. and Mitchell, 1917, the glabella tapers posteriorly; in *C. packhami* it is parallel-sided.

Remarks: The systematic position of *C. silverdalensis* and *C. sculptus* is a little uncertain. Henningsmoen (p. O *431*, in Moore, 1959) states that *Cheirurus* (*Crotalocephalus*) has fixigenae narrower than the occipital ring, with all the glabellar furrows crossing the axis. *C.* (*Cheirurus*) has fixigenae wider than the occipital ring, and only the pre-occipital glabellar furrow crosses the axis. In both *Crotalocephalus silverdalensis* and *C. sculptus* there are three trans-glabellar furrows. However, the dimensions of the cephala figured by Etheridge Jr. and Mitchell clearly show that the fixigenae are wider than the occipital ring. If Henningsmoen's diagnoses are accepted, therefore, these facts throw some doubt on the validity of the subgenera.

Family CALYMENIDAE Burmeister, 1843

Subfamily CALYMENINAE Burmeister, 1843

Gravicalymene Shirley, 1936

Type species: *G. convolva* Shirley, 1936, p. 409. Upper Bala, Llandeilo, Wales.

Gravicalymene australis (Etheridge fil. and Mitchell, 1917)

Plate I, figs. 5*a*, *b*

1917. *Calymene australis* Etheridge fil. and Mitchell, p. 481, Pl. XXIV, figs. 1–7, 9; Pl. XXVII, fig. 1.

1948. *Gravicalymene australis* (Etheridge and Mitchell); Gill, p. 69, Pl. VIII, figs. 9–12.

Lectotype: Specimen figured Etheridge Jr. and Mitchell, 1917, Pl. XXIV, fig. 1; topmost Hume " Series ", Yass; Upper Silurian. Subsequent designation Gill, 1948, p. 70. Specimen in the Australian Museum collection.

Material (Garra Formation): SU 6933, 6941 to 6949, 7900 to 7902; Mountain Waterhole Creek, ph. of Curra, west of road. SU 6940; Loombah Creek, por. 35, ph. of Catombal, 90 yds. east of por. 15. SU 6938; gully, por. 45, ph. of Catombal, 30 yds. east of por. 38.

Description: Of the 15 incomplete specimens available, a large cephalon from Mountain Waterhole Creek is the best preserved (see Pl. I). Although a little distorted, this is typical of the species, with a quadrate frontal lobe, and axial furrows only gently diverging posteriorly. The deep crescentic hollow which exists on the librigena, just forward of the postero-lateral suture, seems to be characteristic of *G. australis*.

Remarks: Five species of *Gravicalymene* have now been described from Australasia. Of these, the closest to *G. australis* is *G. angustior* (Chapman, 1915). Indeed, Etheridge Jr. and Mitchell (1917) considered that the two species might prove to be synonymous. Shirley (1938), in describing *G. angustior* ? from the Baton River beds of New Zealand, compared his specimen closely with *G. australis*, and placed the species in synonymy. Gill (1945) did

likewise in his paper on Victorian Calymenidae, but in 1948, when the type specimens became available, he concluded that the two species were distinct. Examination of published figures reveals the following criteria, additional to those given by Gill (1948). In *G. australis* the *3p* glabellar lobes are larger and more clearly separated from the axis of the glabella than in the other species, and the frontal lobe is more quadrate in outline.

Shirley's specimen is closer to *G. angustior* than to *G. australis*, but the glabella is relatively wider posteriorly than in both these species.

G. australis is known from the Hume " Series " of Yass, and from the Eldon Group, on the Lyell Highway 12 miles from Queenstown, western Tasmania (Gill, 1948). Gill considered that locality to be on the Siluro-Devonian boundary, but Philip (1960*a*, p. 154) regarded the fauna as Upper Silurian. The present specimens are consequently the first from undoubted Devonian rocks.

Calymene Brongniart, 1822

Type species: *C. blumenbachi* Brongniart, 1822. Middle Silurian.

Calymene, sp. nov. ?

Plate I, fig. 6

Holotype: SU 6930; Mousehole Creek, por. 221, ph. of Boree Cabonne, co. of Ashburnham; 780 yds. south-east of road bridge.

Description—Cephalon: The cephalon is short, wide, crescentic, and occupies about one-fifth the total length of the carapace. The width is three times the sagittal length, 2·2 times the overall length of the cephalon. The glabella is convex, its widest place being across the pre-occipital lobes. The sides converge slightly towards the rounded frontal lobe, which overhangs the very narrow anterior border. The *1p* lateral lobes are large, rounded, and flank the narrow (*tr.*) subdued occipital ring. The *1p* furrows are narrow and deep; they slant rearwards, and may unite with the occipital ring. Unfortunately the axis of the glabella has been completely eroded, so this feature is uncertain. The *2p* lobes are smaller than the *1p* lobes, more quadrate, and slightly papillate. Both the *1p* and *2p* furrows expand longitudinally at their adaxial ends, further separating the *2p* and *3p* lobes. The *3p* lobes are mere abaxial swellings of the glabellar sides, not extending on to the upper surface. The *3p* furrows are very shallow and short. The frontal lobe is short, slightly expanded, and strongly convex anteriorly. The axial furrows are narrow.

The fixigenae are flat-topped, with steeply plunging antero-lateral faces and more gently convex postero-lateral areas. Low eye ridges mark the lines of geniculation. Eyes unknown, but probably small. Forward of the eyes the sutures converge slightly; their post-ocular sections sweep out and back in a wide curve, to cut the margin at the sharp genal angles. Genal spines do not occur. The posterior and lateral borders are flat, wide, and inconspicuous, contrasting with the evenly convex narrow anterior border, which is separated from the overhanging glabella by a narrow, rather deep border furrow. The librigenae are unknown, but were probably narrow, crescentic, and steeply sloping. Surface sculpture is tuberculate.

Thorax: The thoracic axis is almost completely eroded, but the two remaining rather distorted posterior rings are strongly arched, with large swellings at their distal ends. The axial furrows are deep and narrow. The pleurae are flat adaxially, steeply inclined to vertical abaxially, their distal ends spatulate. The anterior pleural bands are strong, laterally directed until just inside the fulcrum, when they (with the remainder of the pleura) slant rather strongly rearwards. The pleural furrow and posterior band are subdued, and parallel the anterior band. There are 12 thoracic tergites.

The thorax is a little narrower than the cephalon anteriorly, and becomes gradually narrower rearwards.

Pygidium: The pygidium is missing, but the outline remains. This is triangular, narrower than the last thoracic tergite, and rather longer than in typical *Calymene*.

Comparison: *Calymene* S.S. is not well represented in Australia, most calymenid species being *Gravicalymene*. *C. bowiei* Gill, 1945, and *C. killarensis* Gill, 1945, both from the basal Devonian of Victoria, are quite distinct from the Garra species; in particular, they possess a much stronger anterior border. *C. duni* Etheridge Jr. and Mitchell, 1917, which was stated to be an exceptionally large *Calymene*, cannot be compared with the Garra species, as the cephalon is unknown.

Until further material of this species becomes available, it is best left unnamed.

Family ODONTOPLEURIDAE Burmeister, 1843

Subfamily ODONTOPLEURINAE Burmeister, 1843

Leonaspis Richter and Richter, 1917

TYPE SPECIES: *Odontopleura Leonhardi* Barrande, 1846, p. 38. Lower Ludlovian Kopanina Limestone, near Beroun, Czechoslovakia.

REMARKS: *Leonaspis* is distinguished from *Odontopleura* by its shorter, more robust librigenal spines, which are slanted rearwards. In *Acidaspis* the spines are directed vertically downwards.

Leonaspis, sp. indet.

Plate I, figs. 3, 4

MATERIAL: SU 6931 (external mould of librigena); por. 4, ph. of Boree Nyrang, co. of Ashburnham, 80 yds. north-west of bridge over Walker's Creek. SU 6939 (portion of librigena); from old road, southern boundary of por. 64, ph. of Catombal, co. of Gordon.

DESCRIPTION: The librigenae are small, crescentic. The lateral borders are thick and relatively wide, bearing a row of small nodes. The librigenal spines are short, rectangular, abruptly truncated distally, and directed slightly rearwards. The lateral border furrows are faint. The librigenae slope steeply upwards to the small, bulbous, crescentic eyes. The upper portions are finely tuberculate. The genal spines are narrow, circular in section, and directed slightly outwards and rather noticeably downwards.

COMPARISON: Prantl and Přibyl (1949, p. 154) noted that *Leonaspis* occurs in Australia, but did not name the species. Etheridge Jr. and Mitchell (1896) described four species of *Odontopleura* from the Silurian of Yass; of these, only *O. rattei* resembles *Leonaspis* sp. This species, however, has the rearmost two or three librigenal spines based on the genal spines, and also has a completely tuberculate cephalon. The tubercles in *Leonaspis* sp. are confined to the upper portions of the librigenae. *Leonaspis* (*Leonaspis*) *dormitzeri* (Hawle and Corda, 1847), from the Silurian of Czechoslovakia is very similar to *Leonaspis* sp., but it also is more strongly tuberculate.

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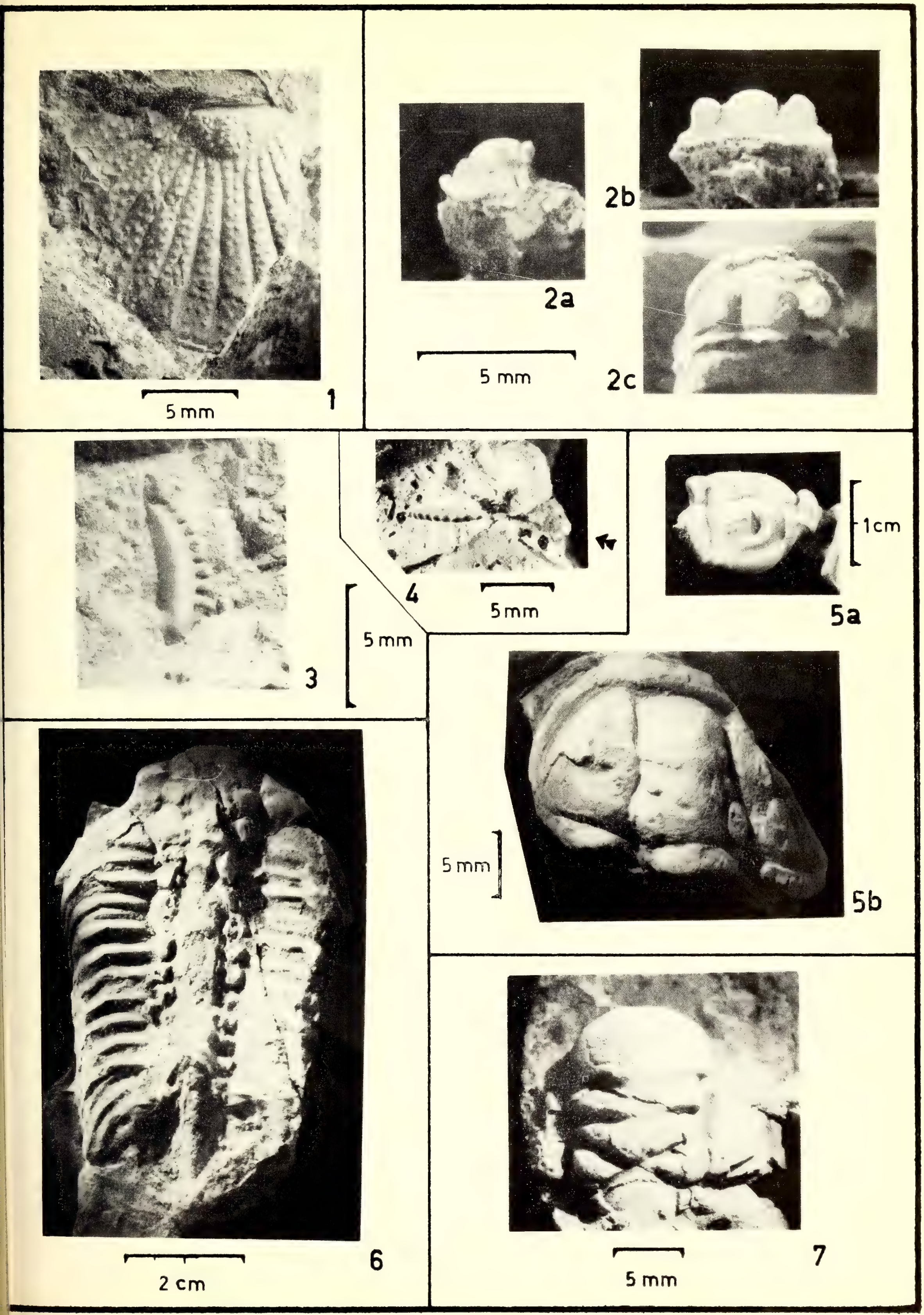
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Explanation of Plate 1

All specimens whitened with ammonium chloride, and illuminated from top left. Localities given in text.

1. *Scutellum* (*Scutellum*), sp. indet. Dorsal view of incomplete pygidium, SU 6932, ×3·2.
2. *Otarion munroei*, sp. nov. Holotype, SU 6934 ; (*a*) lateral, (*b*) anterior, (*c*) dorsal views, ×5·2.
3. *Leonaspis*, sp. indet. Dorsal view of incomplete librigena, SU 6939, ×4·0.
4. *Leonaspis*, sp. indet. Lateral view of mould of librigena, SU 6931 ; genal spine indicated by arrow ; ×2·4.
5. *Gravicalymene australis* (Etheridge fil. and Mitchell, 1917). Cephalon, SU 6941, distorted by compaction of enclosing shale ; (*a*) lateral view, ×1·4 ; (*b*) dorsal view, ×2·2.
6. *Calymene*, sp. nov. ? Dorsal view of carapace, holotype SU 6930 ; the impression of the pygidium is faintly visible ; ×1·0.
7. *Cheirurus* (*Crotalocephalus*) *packhami*, sp. nov. Dorsal view of incomplete, partly decorticated cephalon, holotype, SU 6901, ×2·3.

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JOURNAL AND PROCEEDINGS OF THE ROYAL SOCIETY OF NEW SOUTH WALES

VOLUME 97 1964 PART 4

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Journal and Proceedings, Royal Society of New South Wales, Vol. 97, pp. 99–105, 1964

Precise Observations of Minor Planets at Sydney Observatory During 1961 and 1962

W. H. Robertson
Sydney Observatory, Sydney

The programme of precise observations of selected minor planets which was begun in 1955 is being continued and the results for 1961 and 1962 are given here. The methods of observation and reduction were described in the first paper (Robertson, 1958). All the plates were taken with the 9-inch camera by Taylor, Taylor and Hobson (scale 116″ to the millimetre). Four exposures were made on each plate.

In Table I are given the means for all four images for the separate groups of stars at the mean of the times. The differences between the results average $0^{s}{\cdot}028 \sec\delta$ in right ascension and $0''{\cdot}32$ in declination. This corresponds to probable errors for the mean of the two results from one plate of $0^{s}{\cdot}012 \sec\delta$ and $0''{\cdot}14$. The result from the first two exposures was compared with that from the last two by adding the movement computed from the ephemeris. The means of the differences were $0^{s}{\cdot}011 \sec\delta$ in right ascension and $0''{\cdot}13$ in declination. No correction has been applied for aberration, light time or parallax but the factors give the parallax correction when divided by the distance. The observers at the telescope were W. H. Robertson (R,) K. P. Sims (S) and Harley Wood (W).

In accordance with the recommendation of Commission 20 of the International Astronomical Union, Table II gives for each observation the positions of the reference stars and the dependences. The columns headed "R.A." and "Dec." give the seconds of time and arc with proper motion correction applied to bring the catalogue position to the epoch of the plate. Star 7901 in observation 491 was assumed to be in error by 10″. The column headed "Star" gives the number from the Yale Catalogue (Vols. 11, 12 I, 12 II, 13 I, 14, 16, 17, 21) and the Cape Catalogue of Faint Stars. I wish to acknowledge the assistance of Mrs. J. Brannigan and Mrs. Y. Lake in the measurement and reduction of some of the plates.

Reference

Robertson, W. H., 1958. *J. Proc. Roy. Soc. N.S.W.*, **92**, 18; *Sydney Observatory Papers*, **33**.

Table I

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
		6 Hebe 1961 U.T.									
419	July	27·78721	01	35	42·598	—01	30	11·78	—0·036	—4·69	R
420	July	27·78721	01	35	42·559	—01	30	11·88			
421	Aug.	14·76628	01	58	40·068	—03	06	57·04	+0·002	—4·48	R
422	Aug.	14·76628	01	58	40·032	—03	06	57·00			
423	Aug.	21·74740	02	05	42·212	—04	06	00·73	—0·013	—4·35	S
424	Aug.	21·74740	02	05	42·168	—04	06	00·96			
425	Sep.	12·70452	02	18	43·326	—08	22	51·12	+0·013	—3·76	W
426	Sep.	12·70452	02	18	43·309	—08	22	51·30			
427	Sep.	20·67634	02	19	28·255	—10	14	06·66	—0·009	—3·50	R
428	Sep.	20·67634	02	19	28·321	—10	14	06·66			
429	Oct.	10·61343	02	12	19·112	—14	38	50·47	—0·020	—2·87	R
430	Oct.	10·61343	02	12	19·127	—14	38	50·30			
431	Oct.	19·57907	02	06	03·884	—16	06	12·22	—0·037	—2·67	S
432	Oct.	19·57907	02	06	03·910	—16	06	12·04			
433	Oct.	25·57533	02	01	30·826	—16	46	21·24	+0·013	—2·56	W

A

TABLE I—*Continued*

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
434	Oct.	25·57533	02	01	30·768	—16	46	22·02			
435	Oct.	30·56221	01	57	46·364	—17	07	13·73	+0·022	—2·52	R
436	Oct.	30·56221	01	57	46·340	—17	07	13·75			
437	Nov.	09·51213	01	51	10·232	—17	13	39·33	—0·035	—2·51	R
438	Nov.	09·51213	01	51	10·274	—17	13	39·22			
439	Nov.	13·49922	01	49	04·249	—17	03	24·30	—0·037	—2·53	S
440	Nov.	13·49922	01	49	04·234	—17	03	24·30			
441	Dec.	05·45449	01	45	29·163	—14	20	01·31	+0·020	—2·92	S
442	Dec.	05·45449	01	45	29·150	—14	20	01·12			
		7 Iris 1961 U.T.									
443	Apr.	11·78793	18	40	55·621	—23	12	34·16	—0·054	—1·61	R
444	Apr.	11·78793	18	40	55·692	—23	12	34·07			
445	May	08·74170	18	48	32·426	—22	24	26·36	+0·019	—1·72	S
446	May	08·74170	18	48	32·454	—22	24	26·34			
447	May	16·71559	18	47	05·706	—22	11	40·02	+0·010	—1·75	W
448	May	16·71559	18	47	05·670	—22	11	39·57			
449	May	22·70626	18	44	48·917	—22	02	36·30	+0·38	—1·78	R
450	May	22·70626	18	44	48·920	—22	02	35·85			
451	June	14·61396	18	27	34·860	—21	29	50·04	—0·020	—1·86	R
452	June	14·61396	18	27	34·795	—21	29	49·40			
453	June	19·60153	18	22	28·432	—21	22	28·86	—0·004	—1·87	S
454	June	19·60153	18	22	28·410	—21	22	28·32			
455	June	26·57804	18	14	58·614	—21	11	48·02	—0·002	—1·90	W
456	June	26·57804	18	14	58·632	—21	11	48·24			
457	July	03·56204	18	07	24·946	—21	00	45·14	+0·026	—1·93	R
458	July	03·56204	18	07	25·026	—21	00	44·94			
459	July	10·52800	18	00	12·874	—20	49	36·97	—0·007	—1·96	S
460	July	10·52800	18	00	12·850	—20	49	37·40			
461	July	19·51612	17	52	02·235	—20	35	51·45	+0·053	—2·00	W
462	July	19·51612	17	52	02·254	—20	35	51·43			
463	July	27·47990	17	46	19·986	—20	25	01·18	+0·019	—2·02	R
464	July	27·47990	17	46	19·918	—20	25	01·30			
465	Aug.	01·46364	17	43	38·129	—20	19	12·11	+0·017	—2·03	W
466	Aug.	01·46364	17	43	38·112	—20	19	11·42			
467	Aug.	08·43635	17	41	05·100	—20	12	30·63	—0·004	—2·05	R
468	Aug.	08·43635	17	41	05·080	—20	12	30·45			
469	Aug.	15·42171	17	40	00·988	—20	07	36·90	+0·013	—2·06	W
470	Aug.	15·42171	17	40	00·944	—20	07	37·40			
471	Aug.	28·40487	17	41	56·036	—20	02	54·96	+0·069	—2·10	S
472	Aug.	28·40487	17	41	55·986	—20	02	55·50			
473	Sep.	04·37400	17	44	55·818	—20	02	09·22	+0·024	—2·08	W
474	Sep.	04·37400	17	44	55·770	—20	02	09·54			
475	Sep.	06·37798	17	46	01·864	—20	02	04·22	+0·053	—2·09	S
476	Sep.	06·37798	17	46	01·821	—20	02	04·68			
		433 Eros 1961 U.T.									
477	Apr.	11·60387	13	58	28·306	—49	47	50·44	—0·022	+2·45	R
478	Apr.	11·60387	13	58	28·264	—49	47	51·08			
479	May	02·52902	13	22	58·950	—45	31	18·97	+0·011	+1·81	R
480	May	02·52902	13	22	58·980	—45	31	19·10			
481	May	08·51761	13	17	08·916	—43	28	31·13	+0·049	+1·49	S
482	May	08·51761	13	17	08·914	—43	28	31·52			
483	May	16·47738	13	13	15·956	—40	35	12·00	—0·017	+1·06	R
484	May	16·47738	13	13	15·944	—40	35	11·80			
		11 Parthenope 1962 U.T.									
485	May	29·81252	22	05	33·484	—11	26	12·46	—0·009	—3·34	W
486	May	29·81252	22	05	33·532	—11	26	11·38			
487	June	06·79143	22	13	32·737	—10	57	34·99	—0·024	—3·40	R
488	June	06·79143	22	13	32·712	—10	57	34·26			

TABLE I—*continued*

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
489	June	12·78371	22	18	42·643	—10	41	19·56	—0·008	—3·44	S
490	June	12·78371	22	18	42·684	—10	41	19·26			
491	June	21·77341	22	24	59·100	—10	26	46·34	+0·023	—3·48	W
492	June	21·77341	22	24	59·104	—10	26	45·96			
493	June	25·75437	22	27	08·751	—10	24	31·96	—0·007	—3·48	R
494	June	25·75437	22	27	08·784	—10	24	32·77			
495	July	04·74123	22	30	29·246	—10	30	05·46	+0·022	—3·47	S
496	July	04·74123	22	30	29·318	—10	30	06·44			
497	July	12·71871	22	31	33·345	—10	48	04·58	+0·017	—3·43	W
498	July	12·71871	22	31	33·298	—10	48	03·96			
499	July	16·69581	22	31	23·939	—11	01	41·42	—0·020	—3·40	R
500	July	16·69581	22	31	23·924	—11	01	41·75			
501	July	24·68614	22	29	41·242	—11	38	07·02	+0·022	—3·31	S
502	July	24·68614	22	29	41·248	—11	38	06·95			
503	Aug.	02·67995	22	25	37·032	—12	32	01·19	+0·088	—3·21	W
504	Aug.	02·67995	22	25	37·026	—12	32	01·21			
505	Aug.	09·62938	22	21	08·670	—13	20	36·40	0·000	—3·06	R
506	Aug.	09·62938	22	21	08·644	—13	20	36·44			
507	Aug.	22·59731	22	10	49·786	—14	57	15·46	+0·033	—2·83	W
508	Aug.	22·59731	22	10	49·787	—14	57	15·42			
509	Aug.	27·57600	22	06	37·089	—15	33	02·57	+0·018	—2·75	R
510	Aug.	27·57600	22	06	37·069	—15	33	02·68			
511	Sep.	03·55885	22	00	56·456	—16	18	51·96	+0·037	—2·64	S
512	Sep.	03·55885	22	00	56·502	—16	18	52·31			
513	Sep.	24·47829	21	49	16·535	—17	46	40·33	—0·011	—2·42	R
514	Sep.	24·47829	21	49	16·492	—17	46	40·04			
515	Oct.	05·46159	21	47	57·380	—17	57	51·08	+0·034	—2·40	S
516	Oct.	05·46159	21	47	57·368	—17	57	50·47			
517	Oct.	11·45684	21	48	47·900	—17	54	00·79	+0·070	—2·42	W
518	Oct.	11·45684	21	48	47·936	—17	54	00·94			
519	Oct.	16·42028	21	50	17·922	—17	45	55·10	—0·007	—2·42	W
520	Oct.	16·42028	21	50	17·927	—17	45	54·98			
521	Oct.	22·41220	21	53	01·320	—17	30	35·45	+0·013	—2·46	R
522	Oct.	22·41220	21	53	01·298	—17	30	35·36			
		40 Harmonia 1962 U.T.									
523	Feb.	28·76480	14	56	14·755	—11	09	50·98	+0·003	—3·37	S
524	Feb.	28·76480	14	56	14·764	—11	09	51·22			
525	Mar.	06·74590	14	58	19·381	—11	08	49·84	—0·009	—3·36	W
526	Mar.	06·74590	14	58	19·416	—11	08	49·13			
527	Mar.	12·73321	14	59	22·374	—11	03	28·75	0·000	—3·38	R
528	Mar.	12·73321	14	59	22·346	—11	03	28·90			
529	Mar.	20·70465	14	59	05·586	—10	49	56·09	—0·020	—3·41	S
530	Mar.	20·70465	14	59	05·554	—10	49	55·72			
531	Mar.	26·69445	14	57	35·491	—10	35	11·56	+0·002	—3·44	W
532	Mar.	26·69445	14	57	35·456	—10	35	12·68			
533	Apr.	02·67796	14	54	27·214	—10	13	36·54	+0·039	—3·50	R
534	Apr.	02·67796	14	54	27·241	—10	13	36·90			
535	Apr.	12·66486	14	47	35·983	—09	36	19·78	+0·076	—3·59	S
536	Apr.	12·66486	14	47	35·998	—09	36	19·70			
537	Apr.	18·63898	14	42	25·677	—09	11	55·82	+0·058	—3·64	W
538	Apr.	18·63898	14	42	25·690	—09	11	56·54			
539	Apr.	25·60287	14	35	43·478	—08	43	17·54	+0·020	—3·70	R
540	Apr.	25·60287	14	35	43·498	—08	43	17·68			
541	May	02·58110	14	28	39·460	—08	16	10·91	+0·026	—3·77	S
542	May	02·58110	14	28	39·492	—08	16	11·24			
543	May	22·51964	14	10	28·212	—07	24	48·78	+0·044	—3·89	S
544	May	22·51964	14	10	28·196	—07	24	48·56			
545	May	29·49161	14	05	55·563	—07	20	15·74	+0·026	—3·89	W
546	May	29·49161	14	05	55·609	—07	20	15·92			
547	June	05·46352	14	02	41·702	—07	23	42·37	+0·005	—3·89	W
548	June	05·46352	14	02	41·706	—07	23	42·20			
549	June	07·46401	14	02	01·616	—07	26	11·32	+0·025	—3·88	W
550	June	07·46401	14	02	01·616	—07	26	11·34			

TABLE I—*continued*

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
551	June	11·44848	14	01	02·888	—07	33	04·59	+0·013	—3·86	R
552	June	11·44848	14	01	02·899	—07	33	04·36			
553	June	21·41682	14	00	37·719	—08	01	01·94	+0·001	—3·80	R
554	June	21·41682	14	00	37·696	—08	01	02·43			
555	June	28·40383	14	01	59·758	—08	28	54·29	+0·016	—3·74	W
556	June	28·40383	14	01	59·769	—08	28	54·29			
557	July	12·36981	14	08	31·024	—09	41	45·55	+0·016	—3·57	R
558	July	12·36981	14	08	31·000	—09	41	45·08			
559	July	20·36760	14	14	16·608	—10	31	43·16	+0·064	—3·46	S
560	July	20·36760	14	14	16·628	—10	31	42·20			

TABLE II

No.	Star	Depend.	R.A.	Dec.
419	368	0·373198	19·089	47·50
	385	0·276696	54·016	15·60
	318	0·350105	31·690	18·72
420	300	0·241710	24·626	20·07
	324	0·403268	31·441	18·79
	380	0·355022	34·533	43·53
421	458	0·278020	23·617	51·29
	462	0·308204	05·030	27·94
	491	0·413775	22·522	07·05
422	452	0·331356	23·977	18·63
	473	0·379204	28·359	09·43
	496	0·289440	39·771	36·64
423	495	0·341049	38·263	36·96
	510	0·444391	17·077	31·42
	522	0·214560	22·276	54·11
424	496	0·308248	39·771	36·64
	507	0·268823	29·994	15·06
	513	0·422930	02·816	51·11
425	501	0·379598	59·835	21·62
	512	0·339614	12·262	16·19
	527	0·280789	49·367	05·43
426	502	0·301926	23·052	16·28
	511	0·462516	31·819	46·18
	529	0·235558	05·766	30·97
427	524	0·400380	26·188	51·21
	540	0·273218	34·370	20·33
	515	0·326402	22·117	44·36
428	521	0·333154	45·476	14·19
	541	0·363132	45·143	57·88
	511	0·303713	31·821	46·18
429	564	0·333154	40·150	34·83
	577	0·245448	34·731	15·70
	601	0·421398	26·099	50·36
430	562	0·251628	22·340	13·27
	599	0·384582	42·349	18·14
	508	0·363791	10·291	42·72
431	541	0·368470	18·008	34·57
	562	0·274503	22·341	13·27
	566	0·357027	55·021	15·07
432	533	0·349310	06·742	18·56
	556	0·327920	16·259	36·40
	574	0·322770	08·164	30·70
433	516	0·374054	13·798	10·88
	528	0·348820	02·036	21·96
	550	0·277126	11·941	55·14
434	519	0·458548	32·852	34·12
	539	0·237602	01·026	33·04
	541	0·303850	18·009	34·58
435	498	0·349603	29·981	09·68
	516	0·412348	13·798	10·88
	547	0·238048	31·019	10·69
436	521	0·245123	13·461	53·97
	505	0·453920	21·600	29·85
	543	0·300957	30·224	59·37
437	461	0·249776	22·212	28·79
	479	0·362570	36·610	04·43
	498	0·387653	29·981	09·68
438	467	0·345146	03·994	09·83
	482	0·317678	44·700	13·44
	500	0·337176	43·632	13·98
439	492	0·372340	38·980	43·31
	459	0·413824	00·476	34·23
	499	0·213836	36·236	10·78
440	442	0·365044	13·677	00·34
	464	0·312524	59·365	48·79
	498	0·322432	29·981	09·68
441	434	0·362738	42·101	44·85
	439	0·294578	01·068	03·69
	473	0·342684	41·536	26·88
442	433	0·266008	24·210	02·59
	444	0·356774	30·505	18·71
	458	0·377218	38·223	06·64
443	12975	0·325558	53·196	06·46
	13005	0·308236	09·379	37·94
	13023	0·366206	32·594	16·51
444	12966	0·333650	13·873	60·04
	13002	0·386490	58·641	08·62
	13039	0·279860	03·717	52·95
445	13058	0·346246	26·525	14·08
	13098	0·286732	31·365	29·72
	13136	0·367022	28·521	45·59
446	13055	0·275528	10·636	33·94
	13126	0·313384	04·271	47·62
	7941	0·411088	51·837	08·26
447	7873	0·296022	03·889	32·30
	7941	0·303856	51·837	08·26
	13110	0·400122	29·385	13·10
448	7872	0·376250	02·955	50·85
	13098	0·279522	31·365	29·72
	13136	0·344228	28·521	45·59

TABLE II—*continued*

No.	Star	Depend.	R.A.	Dec.
449	13023	0·287025	32·594	16·50
	13114	0·284058	45·145	14·24
	7882	0·428917	04·618	48·14
450	7872	0·413442	02·955	50·85
	7941	0·252964	51·837	08·26
	13055	0·333594	10·636	33·94
451	7708	0·448498	07·851	56·17
	7756	0·300646	37·877	50·79
	12855	0·250856	30·616	30·88
452	7709	0·346718	07·162	36·23
	7782	0·255236	31·116	54·86
	12814	0·398046	33·341	39·71
453	7670	0·205832	07·168	46·07
	7673	0·470918	14·519	43·52
	7708	0·323250	07·851	56·17
454	7650	0·265106	59·589	30·33
	7689	0·431697	45·042	31·36
	7709	0·303197	07·162	36·23
455	7542	0·335196	13·888	33·85
	7630	0·349942	09·673	44·48
	7636	0·314862	34·295	21·61
456	7563	0·241785	39·879	46·57
	7603	0·503636	54·663	26·44
	7640	0·254579	15·206	19·09
457	7457	0·331636	05·759	19·56
	7526	0·337197	54·470	46·89
	7542	0·331167	13·888	33·85
458	7476	0·342070	35·552	57·88
	7478	0·283596	42·162	05·16
	7570	0·374334	02·929	15·87
459	7384	0·315787	32·163	36·00
	7404	0·266942	08·095	57·63
	7472	0·417270	20·573	30·57
460	7375	0·298622	28·810	12·13
	7412	0·305905	21·282	50·47
	7473	0·395472	26·934	42·57
461	7316	0·297861	50·110	49·53
	7334	0·385024	49·103	41·20
	7384	0·317114	32·163	36·00
462	7311	0·314298	01·794	15·06
	7353	0·308714	24·905	13·18
	7358	0·376987	15·541	34·95
463	7279	0·405084	42·204	06·58
	7316	0·374288	50·110	49·53
	7315	0·220628	46·194	59·31
464	7288	0·282413	43·987	48·74
	7291	0·389892	25·569	54·75
	7334	0·327695	49·103	41·20
465	7261	0·358654	44·202	02·75
	7286	0·374712	42·695	31·05
	7315	0·266634	46·194	59·31
466	7266	0·352678	45·861	25·55
	7281	0·356682	54·047	25·74
	7311	0·290640	01·794	15·06
467	7244	0·212338	52·125	20·78
	7289	0·362066	01·318	09·83
	7263	0·425596	11·785	06·95
468	7245	0·428213	58·884	02·20
	7281	0·219120	54·047	25·74
	7288	0·352667	43·987	48·74
469	7244	0·359726	52·125	20·78
	7249	0·298707	20·675	57·16
	7288	0·341566	43·986	49·29
470	7235	0·246085	49·894	45·24
	7289	0·319722	01·318	09·83
	7257	0·434193	26·502	46·77

No.	Star	Depend.	R.A.	Dec.
471	7244	0·248796	52·125	20·78
	7304	0·319868	28·086	58·79
	7269	0·431336	55·624	07·22
472	7245	0·366182	58·884	02·20
	7286	0·340772	42·695	31·05
	7296	0·293046	47·962	50·55
473	7269	0·297304	55·624	07·22
	7315	0·356499	46·194	59·32
	7291	0·346196	25·569	54·75
474	7261	0·301768	44·151	02·48
	7303	0·287701	42·130	48·09
	7312	0·410531	13·499	08·44
475	7279	0·425582	42·222	05·88
	7309	0·229194	39·378	59·41
	7320	0·345225	03·175	53·13
476	7289	0·486456	01·318	09·84
	7296	0·246794	47·962	50·55
	7334	0·266750	49·152	40·72
477	11611	0·340003	49·91	45·2
	11649	0·349620	35·91	09·6
	11737	0·310377	23·09	45·5
478	11638	0·353375	20·14	23·6
	11655	0·387606	55·31	58·0
	11708	0·259019	50·28	27·4
479	10943	0·366035	56·49	41·0
	10994	0·265090	23·16	21·7
	11069	0·368874	27·02	41·8
480	10957	0·317470	39·39	07·6
	11019	0·446096	44·92	09·0
	11036	0·236434	40·00	26·4
481	10873	0·286981	27·50	32·2
	10896	0·480242	48·23	44·3
	10945	0·232777	57·02	46·4
482	10867	0·305884	57·00	25·6
	10902	0·412430	31·96	28·4
	10927	0·281686	58·80	43·5
483	10768	0·236760	37·33	03·6
	10849	0·242738	49·37	50·2
	10865	0·520502	39·85	34·4
484	10752	0·284626	03·89	42·8
	10889	0·280204	26·87	29·2
	6356	0·435170	58·39	08·6
485	7806	0·249817	21·305	31·04
	7827	0·372482	28·210	17·21
	7838	0·377701	05·921	17·36
486	7813	0·358749	14·216	44·60
	7819	0·269713	25·906	41·75
	7836	0·371538	53·678	37·83
487	7858	0·356316	54·092	05·70
	7862	0·371538	51·266	46·33
	7878	0·272146	38·422	30·69
488	7843	0·307558	55·768	53·16
	7873	0·432280	11·199	31·71
	7876	0·260162	15·692	29·08
489	7878	0·412586	38·422	30·67
	7889	0·321694	14·441	47·17
	7893	0·265720	16·922	19·66
490	7867	0·299108	03·526	06·87
	7891	0·321726	09·559	33·14
	7892	0·379166	08·977	28·01
491	7901	0·319735	53·082	06·69
	7933	0·353710	14·083	09·16
	7938	0·326555	40·238	08·70
492	7915	0·386316	46·402	16·85
	7918	0·281074	10·295	50·38
	7941	0·332610	04·752	01·92

TABLE II—*continued*

No.	Star	Depend.	R.A.	Dec.	No.	Star	Depend.	R.A.	Dec.
493	7915	0·214108	46·401	16·85	515	9298	0·441737	41·615	14·33
	7946	0·438808	36·237	05·88		9350	0·309120	36·695	38·82
	7953	0·347083	38·807	20·12		8199	0·249142	44·239	51·32
494	7918	0·272332	10·295	50·38	516	9323	0·418159	27·051	50·06
	7938	0·463200	40·237	08·70		9324	0·432536	29·027	40·08
	7959	0·264468	02·647	45·45		9343	0·149304	44·187	10·83
495	7953	0·406312	38·807	20·12	517	9323	0·260247	27·051	50·06
	7956	0·319266	47·940	52·53		9326	0·380952	53·541	51·77
	7974	0·274422	01·038	50·03		9343	0·358800	44·187	10·83
496	7941	0·322242	04·751	01·91	518	9310	0·369444	31·376	00·29
	7965	0·315676	42·784	48·76		9350	0·213785	36·695	38·82
	7969	0·362082	27·647	50·42		8199	0·416771	44·239	51·32
497	7950	0·187178	27·266	47·86	519	9326	0·446960	53·541	51·77
	7967	0·508641	09·369	42·21		9367	0·246729	20·920	33·92
	7969	0·304181	27·647	50·42		8199	0·306311	44·239	51·32
498	7956	0·450917	47·940	52·53	520	9324	0·322062	29·027	40·08
	7961	0·200856	13·186	55·03		9350	0·273662	36·695	38·82
	7974	0·348226	01·038	50·03		8207	0·404276	58·202	13·50
499	7956	0·290243	47·940	52·53	521	8199	0·329324	44·239	51·32
	7964	0·386971	42·811	33·12		8239	0·342894	34·084	21·38
	7969	0·322786	27·647	50·42		9350	0·327782	36·695	38·82
500	7945	0·269273	24·192	36·66	522	9343	0·426503	44·186	10·83
	7967	0·503572	09·369	42·22		8211	0·208966	17·352	09·96
	7980	0·227155	27·338	26·52		8241	0·364531	41·321	00·23
501	7947	0·315592	49·784	18·65	523	5235	0·342406	19·314	23·90
	7949	0·311004	14·314	57·77		5246	0·391068	48·842	58·42
	7969	0·373404	27·647	50·42		5266	0·266526	21·240	20·12
502	7932	0·358776	13·048	40·03	524	5226	0·352569	09·524	34·88
	7950	0·301760	27·267	47·86		5245	0·326270	33·389	14·38
	7980	0·339463	27·338	26·52		5269	0·321166	19·804	16·49
503	7913	0·231602	28·600	18·49	525	5253	0·272691	01·698	41·19
	7919	0·340952	17·783	19·39		5259	0·476516	00·474	57·43
	7947	0·427446	49·784	18·65		5269	0·250794	19·804	16·49
504	7910	0·257184	43·763	52·12	526	5246	0·447891	48·842	58·42
	7931	0·392556	10·841	04·63		5265	0·261167	00·730	18·85
	7942	0·350259	06·359	13·73		5273	0·290942	34·332	48·57
505	8347	0·416275	15·572	03·00	527	5259	0·458519	00·474	57·43
	8385	0·145919	01·108	24·11		5266	0·254837	21·240	20·12
	7907	0·437806	15·535	13·16		5273	0·286644	34·332	48·57
506	7884	0·370733	00·898	48·98	428	5250	0·424868	40·431	44·86
	7921	0·174106	34·996	49·98		5265	0·288580	00·730	18·85
	8370	0·455160	23·241	07·77		5283	0·286551	44·567	24·42
507	8292	0·289780	06·596	03·87	529	5253	0·248924	01·698	41·19
	8305	0·350249	24·804	07·13		5258	0·368826	54·971	34·21
	8325	0·359971	13·975	52·82		5273	0·382250	34·332	48·57
508	8299	0·306654	30·303	21·38	530	5245	0·236181	33·389	14·38
	8301	0·383882	52·592	17·44		5266	0·504773	21·241	20·12
	8317	0·309464	19·290	07·28		5275	0·259046	48·425	43·72
509	8272	0·309874	15·442	36·41	531	5250	0·234704	40·431	44·86
	8289	0·477224	01·204	24·97		5254	0·345210	09·201	30·25
	8306	0·212902	36·117	17·50		5260	0·420086	27·811	09·52
510	8279	0·368339	09·373	47·36	532	5245	0·397980	33·389	14·39
	8286	0·389856	58·496	22·44		5253	0·362042	01·698	41·20
	8301	0·241805	52·592	17·44		5275	0·239978	48·425	43·72
511	8238	0·323944	31·617	26·29	533	5220	0·322406	38·834	42·45
	8254	0·234491	06·323	06·74		5260	0·377680	13·061	21·79
	8279	0·441566	09·373	47·36		5234	0·299914	44·249	21·73
512	8260	0·214112	44·662	40·81	534	5227	0·385425	16·497	19·95
	8266	0·384111	02·617	21·25		5251	0·256065	46·563	19·19
	8267	0·401777	28·928	20·01		5239	0·358510	03·780	09·18
513	9310	0·272113	31·376	00·29	535	5195	0·410197	12·467	05·59
	9350	0·237398	36·695	38·82		5203	0·291532	28·996	45·89
	8199	0·490489	44·239	51·32		5219	0·298271	37·672	55·24
514	9323	0·318615	27·051	50·06	536	5186	0·253418	24·764	24·54
	9326	0·145727	53·540	51·77		5213	0·344656	34·902	43·06
	9343	0·535658	44·187	10·83		5215	0·401926	46·118	39·89

TABLE II—*continued*

No.	Star	Depend.	R.A.	Dec.	No.	Star	Depend.	R.A.	Dec.
537	5157	0·229616	23·978	25·63	549	4981	0·317907	00·219	52·23
	5180	0·323050	45·738	30·86		4998	0·356568	20·182	09·29
	5185	0·447334	15·359	10·67		5010	0·325525	38·388	40·56
538	5159	0·188554	00·221	47·74	550	4976	0·310179	23·735	51·86
	5174	0·498050	25·790	10·86		4991	0·386011	29·510	54·96
	5187	0·313396	29·188	14·18		5017	0·303810	24·749	04·47
539	5131	0·270952	45·765	27·71	551	4981	0·322322	00·218	52·23
	5144	0·448468	23·338	19·86		4990	0·377466	26·697	16·14
	5161	0·280580	07·080	03·15		5003	0·300212	44·584	29·84
540	5127	0·239462	26·621	24·71	552	4976	0·400219	23·735	51·86
	5146	0·435317	31·998	34·25		4991	0·347420	29·510	54·96
	5157	0·325221	23·978	25·63		5010	0·252361	38·388	40·55
541	5102	0·433552	30·252	01·66	553	4971	0·289462	51·394	36·15
	5116	0·294784	40·502	07·63		4978	0·335220	31·827	42·81
	5128	0·271663	35·371	38·77		5010	0·375317	38·388	40·55
542	5103	0·467979	41·310	33·46	554	4977	0·241497	27·844	26·98
	5118	0·275534	53·728	14·44		4982	0·451002	09·436	09·13
	5131	0·256487	45·765	27·71		5009	0·307500	29·357	07·23
543	5021	0·312396	18·953	26·60	555	4983	0·314534	10·088	44·63
	5031	0·249230	52·526	24·61		4995	0·372591	09·771	21·13
	5043	0·438374	03·511	00·94		5010	0·312875	38·388	40·55
544	5024	0·331543	28·345	17·48	556	4976	0·400890	23·735	51·86
	5035	0·348258	39·596	39·63		4999	0·300562	24·508	40·20
	5048	0·320199	21·931	47·59		5017	0·298548	24·749	04·47
545	5005	0·280592	29·630	24·41	557	5014	0·459098	06·589	59·36
	5017	0·351648	24·749	04·47		5028	0·236460	49·620	13·91
	5021	0·367761	18·953	26·60		5041	0·304442	54·301	55·95
546	5003	0·460713	44·585	29·84	558	5015	0·361678	10·825	43·85
	5025	0·327900	50·995	27·64		5026	0·236827	29·436	07·50
	5031	0·211386	52·526	24·61		5033	0·401495	38·154	37·09
547	4981	0·303537	00·218	52·23	559	5045	0·218468	10·463	27·11
	4998	0·360274	20·182	09·29		5022	0·454312	15·202	23·96
	5017	0·336189	24·749	04·47		5039	0·327220	25·935	51·42
548	4983	0·323216	10·089	44·63	560	5005	0·223500	49·594	14·47
	4991	0·327206	29·510	54·96		5031	0·315382	41·937	19·46
	5020	0·349578	04·889	00·32		5066	0·461118	37·749	33·00

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Quaternary Sedimentation by Prior Streams on the Riverine Plain, South-west of Griffith, N.S.W.

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Summary—The final phase of alluvial deposition by prior streams on the Riverine Plain south-west of Griffith, N.S.W., is described. Streams are classified according to depth and size of streambed sediments. The entire sequence is attributed to a gradually waning period of fluviatile deposition, featuring frequent stream diversion, which culminated in a period of relative aridity when aeolian sand deposition occurred. Radio carbon datings of wood samples from the youngest prior streams are recorded. Streambed sections are presented in diagrams demonstrating (i) width and depth relative to measured surface levels and (ii) probable mutual relationships of the streams.

Introduction

The area investigated comprises the Benerembah Irrigation District and non-irrigated country between the Hay railway line and the Murrumbidgee River (see Fig. 1).

The area consists of deep alluvial unconsolidated sediments which are part of a broad alluvial fan sloping at 2 ft. to the mile in a westerly direction. The stream system responsible for this deposition is now non-functional and consists of prior streams. Micro-topographic variations occur on the alluvial plain in the form of relic streambeds, levees and floodplains. The latter display further micro relief caused by gilgais.

This primary configuration has been altered by aeolian processes which account for the major relief in the area. Sand dunes up to 20 ft. in height and low sheet deposits were derived from the prior streams by deflation of streambeds and levees. Also mounds of residual levee soil occur as a result of this process of deflation on the prior levees.

Topographic and other surface details of prior streams have previously been described and mapped as "well drained depressions" by Smith *et al.* (1943), Smith (1945), Johnston (1953) and Churchward and Flint (1956).

Butler (1950) put forward the theory of deposition by prior streams on a regional basis, while Langford-Smith (1958) has mapped prior (Murrumbidgee) streams in more detail. Pels (1960) mapped prior streams in the southern part of the Murrumbidgee Irrigation Areas and discussed the stratigraphy of local alluvial sediments.

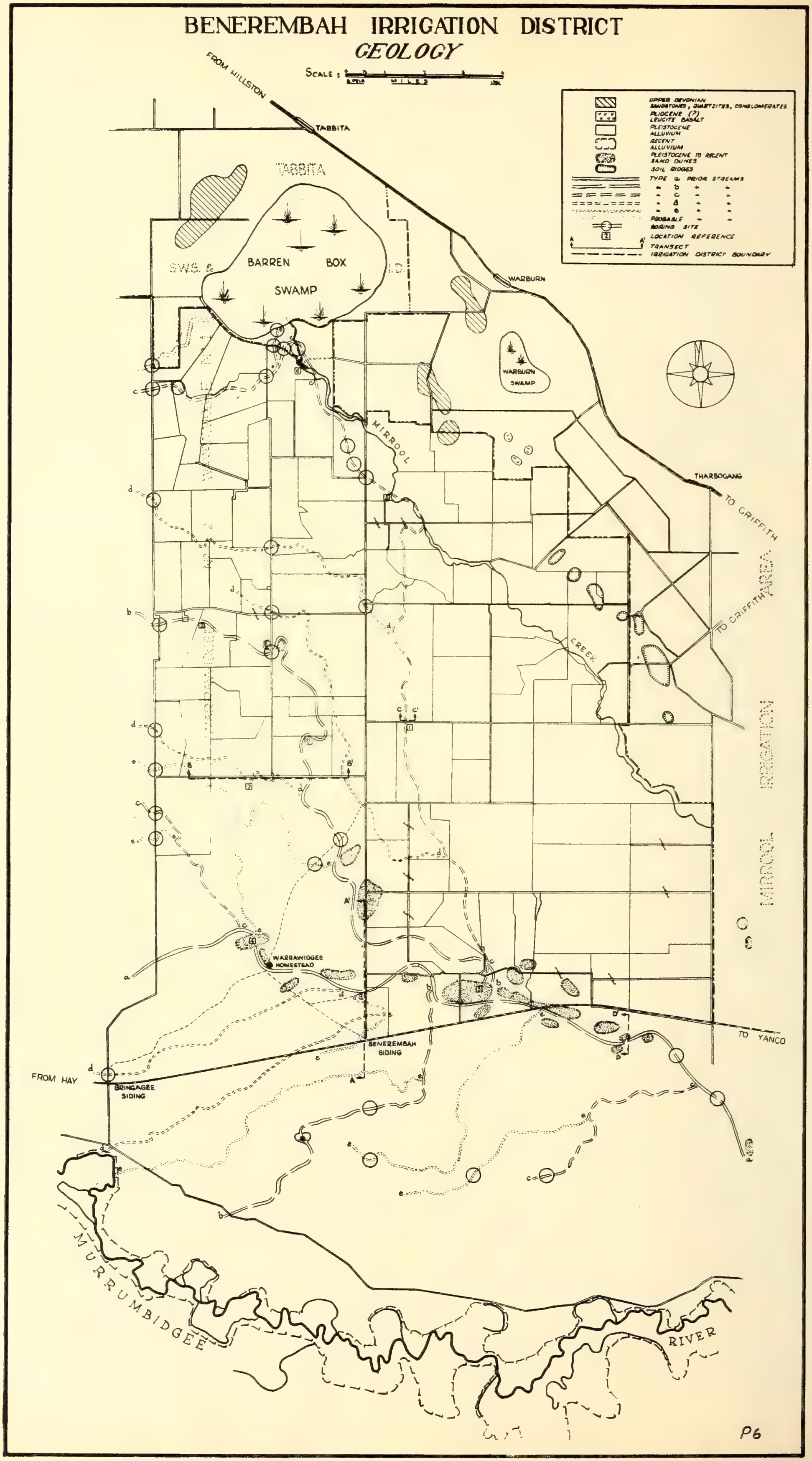
The aim of this investigation was to map the stream system in detail and to determine whether individual stream characteristics could be used as a basis for their classification in terms of mutual relationships.

This involved mapping of the streams on a base plan with the aid of aerial photographs, boring of transects across the streams to determine their lateral extent and depth in relation to measured surface levels; the digging of pits in a search for carbon samples for age determinations and to observe stratification of streambed sediments on the pit faces and general observations on the geomorphology of the area.

The Pattern of Prior Streams

The prior stream system can be readily traced from aerial photographs although location in the field is often difficult. The stream relics form a distributory system of branching streams typical of an aggradational land form (see Fig. 1). Transects bored normal to their former direction of flow have revealed a variation in depth between the various streams. It appears that all had an initial period of down-cutting, as coarse stream deposits almost invariably lie in a channel incised into sediments of heavy texture which are delineated, in the vertical plane, by a well-defined break from heavy clay to coarse sand and gravel. The variation in depth of these coarse sediments from one stream to the other, together with the pattern of streams on the plain, suggests that frequent diversion took place.

The stream system observable on the surface in this area can be subdivided into five classes, each class representing streams of characteristic depth of coarse streambed sediments. It is likely that further buried streams occur at greater depth. The origin of the five types of


BENEREMBAH IRRIGATION DISTRICT
GEOLOGY
SCALE
MILES
UPPER DEVONIAN
SANDSTONES, QUARTZITES, CONGLOMERATES
PLIOCENE (?)
LEUCITE BASALT
PLEISTOCENE
ALLUVIUM
RECENT
ALLUVIUM
PLEISTOCENE TO RECENT
SAND DUNES
SOIL RIDGES
TYPE a PRIOR STREAMS
b
c
d
e
PROBABLE
BORING SITE
LOCATION REFERENCE
TRANSECT
IRRIGATION DISTRICT BOUNDARY
FROM HILLSTON
TABBITA
BARREN BOX
SWAMP
WARBURN
WARBURN SWAMP
MIRROOL
CREEK
THARBOGANG
TO GRIFFITH
MIRROOL IRRIGATION AREA
WARRAWIDGEE HOMESTEAD
BENEREMBAH SIDING
TO YANCO
FROM HAY
BRINGAGEE SIDING
MURRUMBIDGEE
RIVER
P6

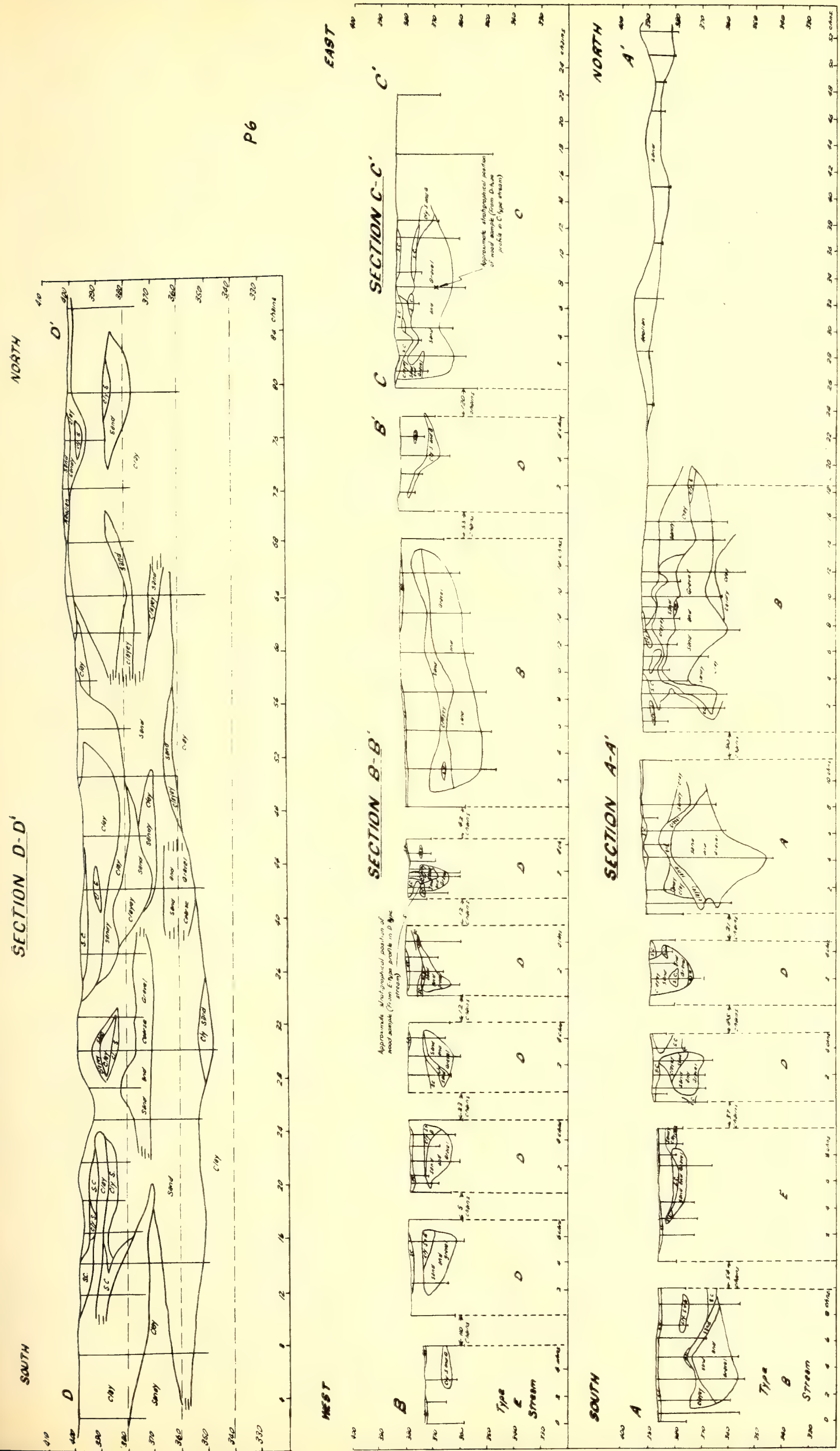

SECTION D-D'
SOUTH
NORTH
D
D'
P6
SECTION C-C'
SECTION B-B'
WEST
EAST
B
B'
C
C'
Type E Stream
SECTION A-A'
SOUTH
NORTH
A
A'
Type B Stream

FIG. 2

streams can all be traced as originating from one major prior stream (D–D1, see Fig. 1).

This prior stream and its westerly flowing extension has a channel depth where measured of 45 ft., it contains very coarse gravel and forms the primary (A-type) stream in this area, the others being secondary, tertiary, quaternary and quinternary. This terminology is confusing in a geological field and will be substituted by alphabetical notation.

The B-type stream which developed by diversion from the A-type stream has a depth to the bottom of the incision of 32 ft. where measured. Subsequent diversion has created the C-type streams with a depth of 21 ft. while further diversion produced D- and E-type streams with depths of 17 ft. and 11 ft. respectively.

The depths are considered to be a reflection of age. All these streams are identical in their mode of deposition but there is a general decline in size and vigour.

The Streambed Sediments

The decline of streams has resulted in a decrease of the size of gravels occurring in the streambeds from the A-type to the E-type streams.

The deep gravels of Gum Creek (Section D–D1), which is an A-type stream, contain water-worn pebbles up to 2 ins. and the gravel size declines to coarse and fine sand together with some fine gravel in the E-type stream beds.

Sand and gravel pits in the B- and C-type streams show that definite horizontal gravel bands occur within the streambed deposits and current bedding in the exposed faces suggests that heavy loads were carried by streams of high velocity.

Diversion was brought about by aggradation of the older streams which caused the stream to break through the levee on to lower surface levels. Evidence of this process is abundant in the field and can be seen in Fig. 1.

Although the age of origin of the streams are distinctly different, the streambed sediments of all streams have a common relationship to some degree.

The diversion of an aggraded stream by the flow breaking through its levees (crevassing) on to lower levels brought about a downcutting action, by lowering the base level of the streambed, above the point of diversion. Evidence from deep gravel and sand pits located in the older streams supports this postulation as definite layering of gravel grading into sand can be observed. From general observations there appears to be a relationship between the depth of younger streams and the levels at which major textural changes occur in the gravel pits of the older streams. The textural changes are thought to represent the base levels of the younger streams. Such layering can be observed in Smith's borrow pit (location 1) and in the borrow pit near Learmonth's Well (location 2).

Boring across the oldest stream (Gum Creek) also revealed gravel layers at levels which approximate the levels of the younger streambeds.

The newly developed section of the stream below the point of diversion and the incised section above that point became in time an aggraded stream.

This process resulted in a complexity of streambed sediments. Downstream from the point of diversion, the older stream contains the original aggraded streambed sediments, while upstream the older streambed sediments were removed to the depth of the younger diverted stream and replaced with younger sediments. Under these conditions, the surface sediments of the streambeds could be of similar age irrespective of whether the channels are of major old streams or minor younger types.

This point would also explain the widespread occurrence and general similarity of road-making loam in shallow pits adjacent to most roads over much of the Riverine Plain.

Figure 3 shows the idealized relationship as is discussed above. Much time was spent on a search for carbon samples, but only two samples were detected which were considered reliable. One sample was obtained from Smith's borrow pit in coarse sand and gravel of a C-type stream 15 feet below the surface (location 1). Another good sample of old wood was found in clayey sand of a D-type stream (location 7) previously described as a Mayrung stream by Butler (1958). This sample was obtained from the streambed at a depth of 5 ft. 6 ins. from the plain surface.

Both samples were submitted to the Institute of Applied Science, Melbourne, for age determination. Results are discussed under the heading "Stratigraphy".

The Levee Sediments

The clear delineation of the prior streams in aerial observation is due to the presence of levees flanking the stream course. These levees are commonly eroded and have a "scalded" appearance. The streambed proper has

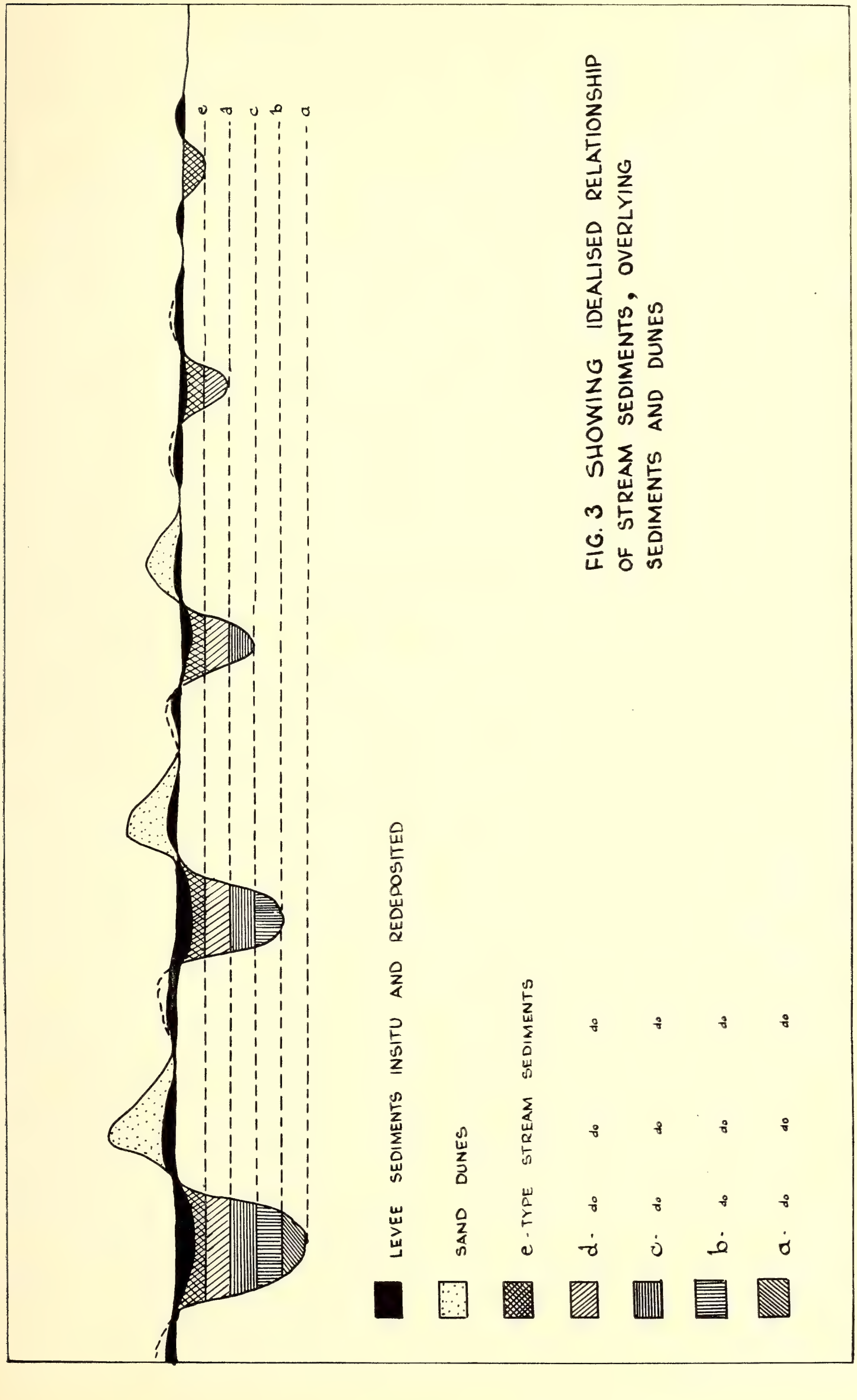


FIG. 3 SHOWING IDEALISED RELATIONSHIP OF STREAM SEDIMENTS, OVERLYING SEDIMENTS AND DUNES

FIG. 3

generally a good grass cover which further accentuates its outline.

The levees are usually deflated but, where they are well developed, minor gullying also occurs, particularly on the steep side, closest to the stream course. Both these forms of erosion and subsequent deposition are considered to have been responsible for the occurrence of heavier textured layers which occur over the streambed sediments between the levees. The levee sediments consist of a red brown sandy clay containing some gravel and lime. Profile development at these locations has resulted in a clay enriched B-horizon which may occur from 6 ins. to 18 ins. below the surface. The scalded areas have been deflated and consist of the exposed B-horizon. Soil mounds of residual A-horizon occur and it appears that these are being gradually worn away during rainstorms and various stages of degradation can be observed. The dispersed materials spread out radially over the surrounding scalded area and are subsequently removed by deflation. Residual gravel, varying in size according to proximity to the streambed, is common on these scalded areas.

Two other types of rock occur scattered over the eroded levees. These are so common that at first examination they appear to be part of the alluvial sediments. Quartzites and other rocks with conchoidal fracture are abundant on the scalded surfaces. These are in the form of sharp edged rock "chips" which are undoubtedly artifacts representing waste from aboriginal implement making.

Another type of stone common on the scalded levees consists of a burnt clay which has a blackened red appearance. This stone is derived from old aboriginal fires and according to the stage of erosion is either scattered or occurs as preserved mounds of hard burned clay protruding from the scalded areas. Charcoal and bones are common in these old fires which appear to have been buried in the levee deposits prior to exposure by deflation. The large number of relic fireplaces on the levees flanking the prior streams and their absence in the streambeds suggest that although the system of prior streams may have been at least seasonally inactive at the time of habitation, surface water occurred possibly in the form of lagoons.

The Overlying Sediments

Streambed sediments of coarse texture may occur on the surface or may be buried by sediments of finer texture to considerable depth. While it is generally true that the older and better delineated streambeds are often overlain by non-streambed sediments to a greater extent than the younger ones, there are many exceptions.

This can be seen in Fig. 2, where a stream of the same age appears on the surface in one part and not in another. This may be due to the removal of sand by wind from certain sections of the stream only. It is possible that removal only took place in those parts where the direction of the stream and that of the prevailing winds coincided. This would account for the scattered occurrence of sand dunes and sand sheets found in close proximity to the streams and suggests that the aeolian sands were largely derived from the final stages of streambed deposition which is also strongly corroborated by the fact that prior stream courses are interrupted by sand dunes overlying the stream surface (location 4, Fig. 1). It can be seen that the stream course is obscured by the dune but emerges again on the downstream side. The absence of obvious diversion patterns suggests that these sand dunes were formed subsequent to the period of prior stream activity.

Although the prior streams are generally situated in relatively elevated winding belts, the preserved stream channel is often a depressed line within this elevated belt. These depressions may support a grass cover in certain locations or a tree cover in others (linear box swamps). It is not clear why this difference in vegetation occurs.

Many shallow linear depressions resemble indistinct prior streams on aerial photographs. Field investigations showed that these elongated depressions lack the characteristic coarse streambed sediments. They appear to be relics of former gullies, and it is usual to find traces of streambed sediments at the base of the former channel. The remainder of the channel is filled with heavier textured sediments to a depth of as much as 10 feet. The latter sediments may be of aeolian origin or the result of slumping of the steep gully walls. Such slumping would produce the broad shape of shallow linear depressions. These postulations are supported by the general absence of levees along this type of depression, which suggests that an aggrading phase was not reached.

Overlying heavier textured sediments were examined (section A) in an A-type stream and were found to be micaceous and non-calcareous throughout the depth of 12 ft. and are described as a micaceous sandy clay loam containing fine

gravel which grades into sand and gravel at greater depth. This gradation to finer sediments could be partly attributed to the waning stream activity, but the bulk of these materials is thought to have been derived from the adjacent levees by deflation, rilling, and minor gullying as described under the previous heading.

Re-deposition of deflated materials from the levees was not restricted to the streambeds since clayey sheet deposits of medium texture are also found overlying the surfaces between the prior streams.

The flood plain component of the entire Riverine Plain is relatively small in the eastern part of the plain and levee and for levee soils are predominant The area of floodplain, characterized by heavy gilgaied soils, becomes much more extensive further west.

This phenomenon was also observed by Butler (1956), although the difference between the eastern and western zones was described in terms of deposition of aeolian sediments derived from a far western source with re-deposition restricted to the eastern zone of the Riverine Plain.

Butler (1958) and van Dijk (1958) have described the aeolian sediments in some detail and it appears from a comparison of their analytical data of both aeolian and riverine clayey sediments that no exact differences can be established. In fact, van Dijk (1958) has shown that more coarse sand occurs in the typical wind-blown deposits (Widgelli-Tabbita phase, Bingar and Cocoparra) than in the riverine deposits (Barellan and Hanwood) interbedded with these aeolian sediments.

The similarity of comparable riverine and aeolian sediments suggests a local fluviatile origin of the aeolian sediments of the plain and on the surrounding hills.

Stratigraphy

Deposition associated with the prior stream system discussed in this paper represents the final phase of a long period of fluviatile deposition.

It has been established (Pels, 1960) that in the lower sequence below the sediments discussed in this paper, sand and gravel deposition has been more extensive and characteristic of deposition by braided streams. There have been a number of these periods of braided stream deposition which were interrupted by periods of deposition by meandering streams when predominantly clay deposition took place with coarse sediments restricted to definite stream channels.

It was suggested that the almost general deposition of sand by braided streams could have been related to the Pleistocene periods of glaciation and that the predominant deposition of clay represented deposition during the interglacial stages. The surface pattern of prior streams has similarities to the latter and it has been shown from evidence presented above that this final period of deposition was a period of continuous and gradually waning stream activity by streams which were frequently diverted. From the admittedly inadequate number of only two carbon datings it appears that although the prior stream pattern in this area is well preserved, it does not indicate a relatively youthful age. Radio carbon dating of carbon samples obtained from a C- and D-type stream (D- and E-type profiles) at locations 1 and 7 have revealed an age in excess of 36,000 years. The size of the second sample allowed it to be sub-sampled so that it was processed twice. Each sample was subjected to three 1,000 minute counts, and all results were in good agreement. The determined age represents the limits of the dating equipment, but it now appears that the final phase of stream deposition took place in the Pleistocene, and that, apart from the deposition along the Murrumbidgee River (see Fig. 1) no deposition has occurred during the Recent.

The established age of the youngest prior streams of greater than 36,000 years suggests that a re-appraisal of the chronology of " K-cycles " of local soils may be in order. It has been stated that the depositional phases of the surface prior streams could be identified with the K_2 cycle (Butler, 1959). The K_2 cycle has been variously stated as representing a period from 3,000 to 7,000 years ago. These ages were largely based on radio carbon datings of layered soils in coastal areas of N.S.W. (Walker, M.Sc. thesis, University of Sydney) and a postulated correlation with inland layered soils. This is clearly not acceptable, and considering the relatively deep incision and limited lateral deposition of the final phases of the prior streams, large areas of the present ground surface must have originated well back into the Pleistocene. This would explain the difficulties experienced in attempts made to correlate " soils chronology " with the existing knowledge of quaternary stratigraphy.

Other findings presented in this paper are to some extent at variance with those of Butler (1958) and van Dijk (1958).

Butler considers the period of deposition, associated with these prior streams, to have

been of three phases, namely, an older phase of stream deposition (Quiamong), a phase of aeolian deposition (Widgelli), and, superimposed on those, a younger phase of stream deposition termed the Mayrung. Stream deposition was said to be associated with a period of widespread aridity and the older stream deposition took place during the period leading into the arid period while younger streams were deposited during the period leading out of this period of aridity.

As has already been stated, the data presented in this paper suggest that the surface prior streams (as shown in Fig. 1 and including both " Mayrung " and " Quiamong " streams) were deposited during a period of continuous but gradually waning stream activity by streams which were frequently diverted. The stratigraphical position of the sand dunes also suggests that the climate changed gradually and culminated in a period of relative aridity when sand dunes were formed overlying the prior stream courses in some locations (see Fig. 1).

Practical Applications

The data obtained are of practical value in the developmental stage the Riverine plains generally are in at this time. It has been shown that roadmaking materials are distributed generally and locations of better drained soils are delineated.

Irrigation is likely to be initially confined to the areas of greatest prior stream activity, i.e., to the eastern zone of the Riverine Plain, as soils associated with the more vigorous parts of the prior streams are superior for irrigation purposes.

This is mainly due to the preponderance of better developed levees over floodplain soils and the greater redistribution of levee soils by deflation.

The influence of the streams on groundwater movement and drainage is of particular interest. In parts of the already developed Irrigation Areas the pattern of sedimentation was similar but the surface evidence, so obvious from aerial observation in the less developed areas, has been obscured here by cultivation. Groundwater movement in the Murrumbidgee Irrigation Areas is very difficult to interpret, and it is in terms of quaternary stratigraphy (of prior streams) that many anomalies in the existing Irrigation Areas may be explained.

The laterally extensive deep sand beds, which were deposited by braided streams, contain water under pressure. Under natural conditions the phreatic surface closely approximates the piezometric levels in these aquifers. It has been found that the shallower sands are separate channel type sand deposits characteristic of meandering streams and that frequent diversion has caused the deposition of sand-filled channels lying at different levels.

Disturbance of the natural equilibrium of the groundwater system by irrigation may cause the piezometric level and phreatic surface to rise, and when this level coincides with channel deposits at higher levels the pattern of groundwater movement would be influenced by movement in the coarse streambed sediments.

Water superimposed on the present groundwater system by irrigation could initially tend to create perched watertables which would display groundwater movement patterns governed by the pattern of prior streams. Such a system would be extremely difficult to interpret unless the sedimentary pattern of prior streams is known.

A further factor which may be of practical application is the intake of surface water into subsurface prior streams. This occurs at location 5 (Fig. 1) and is also likely to occur at location 6. It can be seen that in the vicinity of location 5 the Mirrool Creek is superimposed on a prior stream and old levees occur on both sides of the Creek. Piezometer readings taken in the prior stream north of there (see Fig. 1) show that this buried stream is fully charged. The prior stream portion south of location 5 is known to be dry, as sandpits are located in it. Similar stream flow losses occur in the vicinity of Willow Dam (location 6) to buried streams running west into the Wah Wah Irrigation District.

Acknowledgements

The manuscript was read for comment by Messrs. H. N. England and S. E. Flint, Water Conservation and Irrigation Commission, and by Mr. T. Talsma and Dr. J. Loveday, C.S.I.R.O.

The assistance of Mr. S. J. Jones, Assistant Field Officer, Water Conservation and Irrigation Commission, is also gratefully acknowledged.

Radio carbon datings were carried out by the Institute of Applied Science, Melbourne.

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Some Applications of Aerial Photographs to the Solution of Topographic and Cartographic Problems

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Abstract—A procedure for the exact location on a topographic map of details identified on aerial photographs is presented. The determination is based on the location on the topographic map of the nadiral point of the aerial photographs by a graphico-numerical solution to the Snellius problem of inverse intersection. From the nadiral points on the topographic map, detailed features may be located by a method of direct intersection.

Introduction

During recent years, aerial photographs have assumed an ever increasing importance in many researches where they are used in conjunction with topographic maps. However, the exact location on the map of details (morphological, geological, archaeological, etc.) identified on the aerial photographs has often proved difficult without the use of the stereo-plotting instruments.

This paper presents a simple procedure for the exact location of such details on the maps without the aid of mechanical plotters, in the case of vertical aerial photographs.

Discussion

The following terms of photogrammetry are used in the discussion. The *principal point, N*, of the photogram. This is the point where the optic axis of the camera meets the photographic plate. It is determined by the intersection of the straight lines joining the collimation marks of the photogram. The *nadiral point, N′*, of the map or ground. This is the point of intersection of the vertical from the centre of the camera's objective with the ground surface.

In the case of vertical aerial photographs the centre of the camera's objective and the principal and nadiral points are colinear and the nadiral point becomes the projection of the principal point on the ground. It is therefore an important feature of vertical photographs that identifiable features subtend equal angles at both the principal and nadiral points of the photogram and map respectively. Further, if the nadiral points can be precisely determined on the topographic map, then the exact location of details from the photograms to the map can be achieved by a method of direct intersection using bearings taken at the principal points of two or more photograms.

The precise determination of the nadiral point may be obtained with a construction which yields a graphical solution to the Snellius problem of inverse intersection by using the auxiliary points of Collins.

Construction

The construction requires for each photogram a minimum of three reference points which are identifiable features accurately located on the map. In Figure 1, A, B and C are the three points identified and located on the photogram (Fig. 1, *a*) and on the map (Fig. 1, *b*). At the principal point N of the photogram the reference points A and B subtend the angle α and the points B and C, the angle β.

The auxiliary point of Collins is obtained by constructing a line through A at the angle β with respect to AB, and a line through B at the angle $(\alpha+\beta)$ with respect to BA as shown in Figure 1, *b*. The intersecting point E, of the constructed lines, is the auxiliary point of Collins.

Since AB subtends an angle α at both E and N′, the nadiral point N′ falls on the circumference of the circle through A, B and E. Hence, BE which subtends the angle β at A also subtends the angle β at N′, and the points N′, E and C are colinear.

The second auxiliary point of Collins, F, which is obtained by a similar construction about the line BC, is colinear with N′ and A. The nadiral point N′ is therefore determined by the intersection of the lines EC and FA.

Although only three points of reference are necessary for the construction, it is preferable to use four points as illustrated in Figure 2.

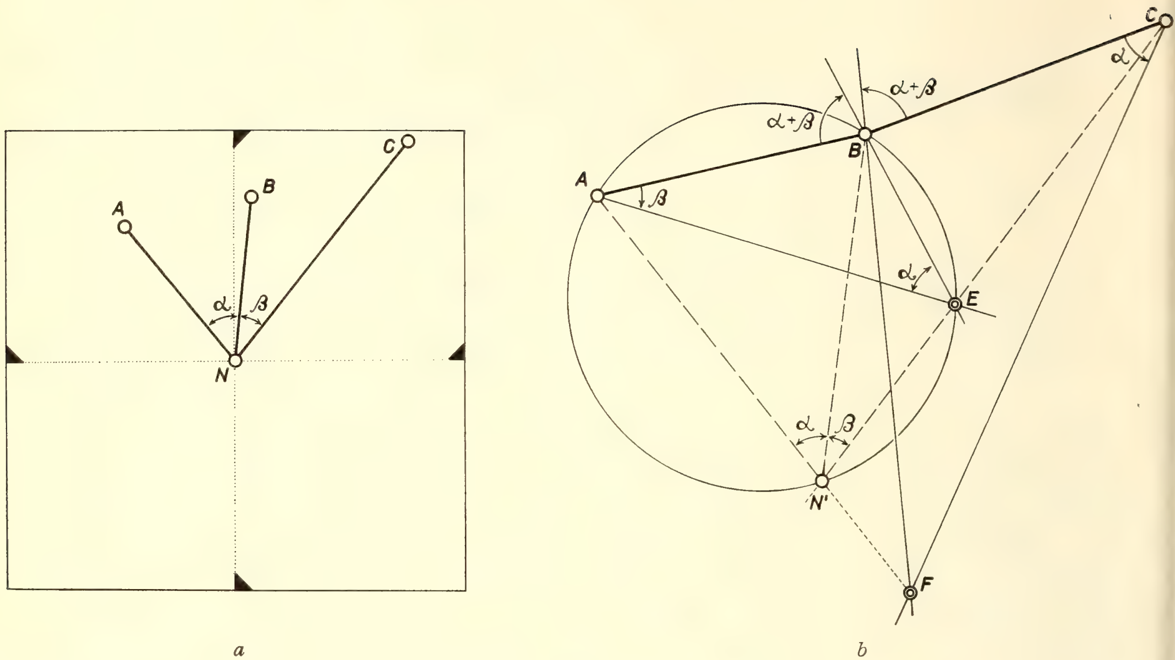

A
B
C
N
α
β
a
A
B
C
E
F
N'
α+β
α+β
α
β
α
β
α
b

Fig. 1

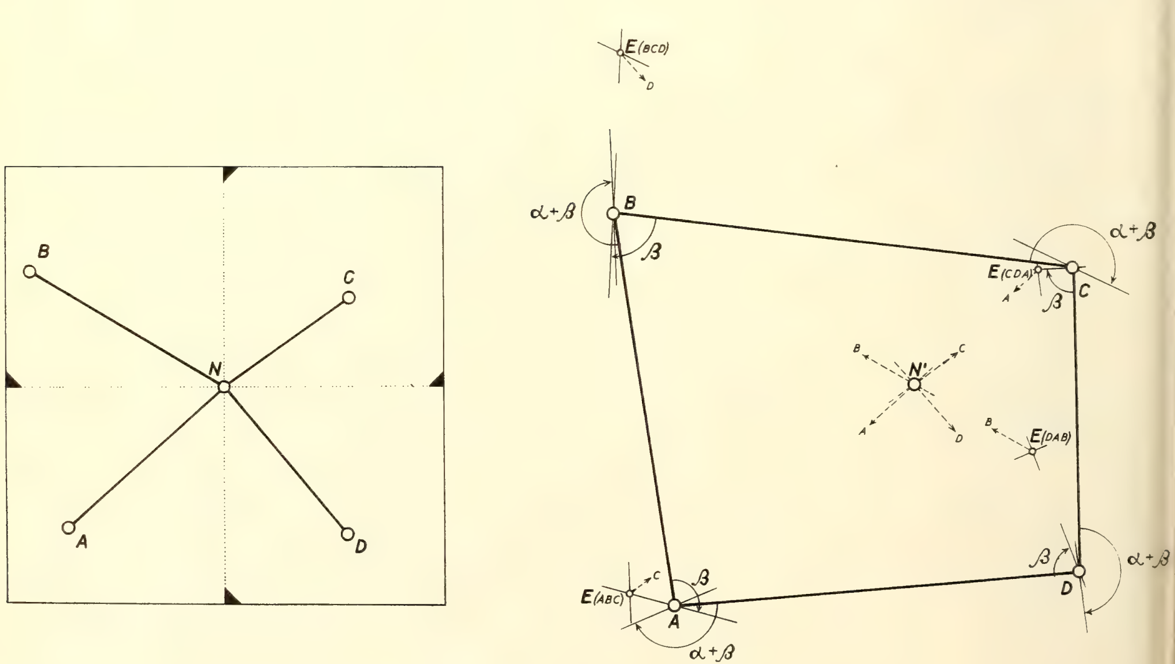
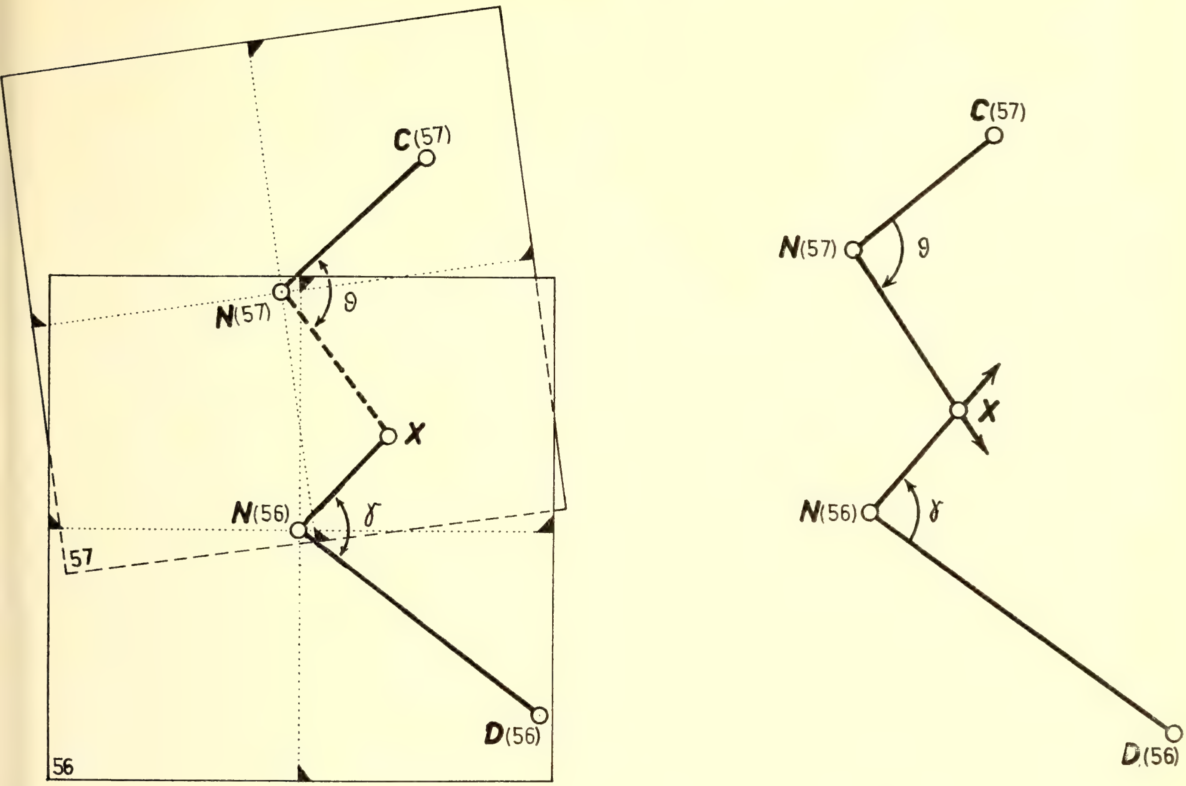

B
C
N
A
D
E(BCD)
B
C
D
A
N'
E(CDA)
E(DAB)
E(ABC)
α+β
β
α+β
β
α+β
β
α+β
β

Fig. 2



a *b*

Fig. 3

In this figure, only the points E of the above construction have been used.

The use of four points improves both the reliability of the determined position of the nadiral point and provides a better distribution of reference points.

Location and Details on the Map

The exact location of details from the photograms to the map is illustrated in Figure 3. An important detail X, occurring on the two photograms (no. 56 and 57) in Figure 3, *a*, subtends angles of θ and γ at their principal points with the directions of the reference points C_{57} and D_{56} as shown. The angles θ and γ from the respective reference points are then constructed at the corresponding nadiral points on the map as shown in Figure 3, *b*. The position of the detail X on the map is defined by the direct intersection of the constructed lines.

Conclusion

All details of interest occurring on two or more photograms may be located in this manner. Also, since the determination is independent of the scale of the map used, it can be applied even to the case of enlargements of the aerial photographs.

Acknowledgement

The writer is greatly indebted to Mr. L. V. Hawkins, School of Applied Geology, University of New South Wales, for helpful discussion of the present paper.

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(Received 6 December, 1962)

Annual Reports

Report of the Council for the year ended 31st March, 1963

At the end of the period under review the composition of the membership was 353 members, 19 associate members and 9 honorary members ; 15 new members were elected. Six members and associate members had resigned and the name of one associate member was removed from the list in accordance with Rule XVIII.

It is with regret that we announce the loss by death of

Dr. Adolph Bolliger (elected 1933),
Mr. Anthony Dadour (elected 1940),
Prof. Francis P. J. Dwyer (elected 1934),
Mr. Frank Leechman (elected 1957),
Mr. Burnett Mander-Jones (elected 1960).

Nine monthly meetings were held. The abstracts of all addresses have been printed on the notice papers. The proceedings of these meetings appear later in this issue of the " Journal and Proceedings ". The members of the Council wish to express their sincere thanks and appreciation to the seven speakers who contributed to the success of these meetings and also to the members who read papers at the November meeting.

The Annual Social Function was held on 28th March at the Sydney University Staff Club and was attended by 54 members and their guests.

The Council has approved the following awards :

The Clarke Medal for 1963 to Dr. Germaine A. Joplin, Geophysics Department, the Australian National University.

The Society's Medal for 1962 to Mr. Harley Wood, Government Astronomer, Sydney Observatory.

The Walter Burfitt Prize for 1962 to Dr. M. F. Glaessner, F.A.A., Geology Department, the University of Adelaide.

The Edgeworth David Medal for 1962 to Mr. R. F. Isbell, of C.S.I.R.O., Division of Soils, Brisbane.

The Liversidge Research Lecture for 1962 entitled " Nucleic Acids : Their Structure and Function " was delivered by Prof. D. O. Jordan, of the Department of Physical and Inorganic Chemistry, the University of Adelaide. The lecture has been published in the " Journal and Proceedings ", v. 96, p. 39.

The Pollock Memorial Lecture for 1962, given under the joint auspices of the Royal Society of New South Wales and the University of Sydney, entitled " Life on Other Planets ", was delivered by Professor F. Hoyle, F.R.S., Plumian Professor of Astronomy, Cambridge University.

The Society has again received from the Government of New South Wales a grant of £750. The Government's interest in the work of the Society is much appreciated.

The Society's financial statement shows a deficit of £117 9s. 4d.

The New England Branch of the Society progressed satisfactorily during the year. Four meetings at which invited speakers were present were held.

Vigorous progress has been handicapped by the decrease in the numbers of distinguished visitors to the University of New England. Unfortunately, funds available are not yet sufficient to pay the expenses of visitors from great distances from Armidale.

The President represented the Society at the Commemoration of the Landing of Captain Cook at Kurnell and also attended the Annual Meeting of the Board of Visitors of the Sydney Observatory.

On 27th July, the President and the Hon. Secretary waited on His Excellency the Governor of New South Wales.

The Society's representatives on Science House Management Committee were Mr. Donegan and Mr. Adamson.

One part of the " Journal and Proceedings " has been published during the year, Volume 96, Part 1, in which appeared three papers.

The Section of Geology held five meetings and abstracts of the proceedings will be published later.

Council held eleven ordinary meetings and attendance was as follows : A/Prof. W. B. Smith-White 10 ; Mr. H. A. J. Donegan 7 ; Mr. A. F. A. Harper 7 ; Prof. R. J. W. Le Fevre 5 ; Mr. W. H. G. Poggendorff 3 ; Mr. J. L. Griffith 11 ; Dr. A. A. Day 8 ; Mr. C. L. Adamson 7 ; Dr. Ida A. Browne 9 ; Father A. G. Fynn 10 ; Dr. N. A. Gibson 6 ; Mr. H. G. Golding 8 ; Mr. J. W. Humphries 9 ; Dr. A. H. Low 5 (absent on leave 6) ; Mr. H. H. G. McKern 11 ; Dr. P. D. F. Murray 0 ; Mr. G. H. Slade 4 ; Dr. A. Ungar 7.

The Library—Periodicals were received by exchange from 398 societies and institutions. In addition the amount of £132 13s. was expended on the purchase of 12 periodicals.

The reorganization of the library is almost complete. This has been achieved by the most strenuous efforts of the Assistant Librarian.

Among the institutions which made use of the library through the inter-library loan scheme were :

N.S.W. Govt. Depts.—Department of Agriculture, Botanic Gardens, Forestry Commission, Main Roads Board, Department of Mines, M.S.W. & D. Board, Department of Public Health, Soil Conservation Service, Sydney County Council, W.C. & I. Commission, Wood Technology Division.

Commonwealth Govt. Depts.—C.S.I.R.O., Head Office, Melbourne ; Library, Canberra ; Division of Animal Physiology, Prospect ; Cunningham Laboratory, Brisbane ; Division of Food Preservation, Ryde ; Division of Irrigation Research, Griffith ; McMaster Laboratory, Sydney ; National Standards Laboratory, Sydney, Division of Oceanography, Cronulla ; Division of Textile Physics, Ryde ; Division of Tribophysics, Melbourne ; Wool Research Laboratory, Geelong ; Australian Atomic Energy Commission ; Bureau of Mineral Resources ; Snowy Mountains Hydro Electric Authority.

Universities and Colleges.—Sydney Technical College, Newcastle University College, University of Adelaide,

Australian National University, Mount Stromlo Observatory, University of Sydney, University of New England, University of New South Wales, University of Queensland, University of Tasmania, University of Western Australia.

Companies—A.C.I., A.W.A. Ltd., A.I. & S. Pty. Ltd., B.H.P. Co. Ltd., C.S.R. Co. Ltd., Ducon Condensors, Electrolytic Zinc Co., I.C.I. Ltd., Johnson & Johnson, J. Lysaght Ltd., Unilever Ltd., Union Carbide Ltd., Wheat Industries Ltd., W. D. & H. O. Wills Ltd.

Research Institutes—Bread Research Institute, M.B.T. Research Laboratories.

Museums and Miscellaneous—The Australian Museum, National Museum of Victoria, South Australian Institute of Technology, Edgeworth David Memorial Library, Cessnock ; Institution of Engineers, Australia ; Institution of Radio Engineers.

J. L. Griffith,
A. A. Day,
Honorary Secretaries.

The Honorary Treasurer's Report

Mr. Chairman, Ladies and Gentlemen,

Please accept my apology for absence from the meeting, which is due to geological fieldwork.

From inspection of the Income and Expenditure Account it will be seen that there is a deficit of £117 9s. 4d. compared with a deficit of £196 last year. However, there is one important feature of this year's accounts which makes direct comparison misleading. This feature is the cost of printing the " Journal and Proceedings ". Owing to the fact that this year's accounts include printing of only three parts of the " Journal and Proceedings ", as opposed to the usual six parts, a provision of £1,000 has been included in the Expenditure Account to cover printing costs of the remainder of Volume 96. Thus while the previous year's accounts dealt with actual expenditure on printing this year's accounts provide for an estimated cost of part of the printing. This situation will be reflected in the finances for the coming year when final adjustments will be made.

Compared with last year, there was a marked drop in revenue from reprints and back numbers of the " Journal and Proceedings ". This was counter-balanced by sale of unwanted periodicals from the Society's library. This income can be regarded as connected with the " Journal and Proceedings " as the material disposed of has been acquired by exchange.

I regret to state that while there has been a slight increase in income from Membership Subscriptions there has been a slight fall in our share of the income from Science House. The most welcome subsidy from the State Government remained constant at £750. Thus the income from our regular sources has remained almost static, while there have been slight rises in our regular items of expenditure such as salaries, postages, general printing, library purchases and miscellaneous expenditure.

In conclusion I would thank our Assistant Secretary, Miss Ogle, for the efficient way in which financial routine has been carried out.

C. L. Adamson,
Honorary Treasurer.

Financial Statement

BALANCE SHEET AS AT 28th FEBRUARY, 1963

LIABILITIES

1962		£ s. d.	£ s. d.
—	Accrued Expenses		1,000 0 0
33	Subscriptions Paid in Advance		25 14 6
104	Life Members' Subscriptions — Amount carried forward		96 15 0
	Trust and Monograph Capital Funds (detailed below)—		
	Clarke Memorial	2,014 0 8	
	Walter Burfitt Prize	1,195 14 11	
	Liversidge Bequest	683 9 9	
	Monograph Capital Fund	4,685 9 4	
	Ollé Bequest	181 12 7	
8,580			8,760 7 3
23,022	Accumulated Funds		22,839 2 5
130	Employees' Long Service Leave Fund Provision		159 19 8
	Contingent Liability (in connection with Perpetual Lease).		
£31,869			£32,881 18 10

ASSETS

1962		£ s. d.	£ s. d.
1,019	Cash at Bank and in Hand		1,986 5 10
	Investments—		
	Commonwealth Bonds and Inscribed Stock—		
	At Face Value—held for:		
	Clarke Memorial Fund	1,800 0 0	
	Walter Burfitt Prize Fund	1,000 0 0	
	Liversidge Bequest	700 0 0	
	Monograph Capital Fund	3,000 0 0	
	General Purposes	1,960 0 0	
8,460			8,460 0 0
130	Fixed Deposit—Long Service Leave Fund		159 19 8
	Debtors for Subscriptions	99 4 6	
	Less Reserve for Bad Debts	99 4 6	
—			—
14,835	Science House—One-third Capital Cost		14,835 4 4
6,800	Library—At Valuation		6,800 0 0
609	Furniture and Office Equipment—At Cost, *less* Depreciation		625 9 3
15	Pictures—At Cost, *less* Depreciation		13 19 9
1	Lantern—At Cost, *less* Depreciation		1 0 0
£31,869			£32,881 18 10

TRUST AND MONOGRAPH CAPITAL FUNDS

	Clarke Memorial £ s. d.	Walter Burfitt Prize £ s. d.	Liversidge Bequest £ s. d.	Monograph Capital Fund £ s. d.	Ollé Bequest £ s. d.
apital at 28th February, 1963	1,800 0 0	1,000 0 0	700 0 0	3,000 0 0	—
Revenue—					
Balance at 28th February, 1962	142 2 2	170 8 7	36 4 5	1,562 6 11	169 7 1
Income for twelve months	72 4 0	40 2 0	28 1 2	123 2 5	42 5 6
	214 6 2	210 10 7	64 5 7	1,685 9 4	211 12 7
Less Expenditure ..	0 5 6	14 15 8	80 15 10	—	30 0 0
Balance at 28th February, 1963	£214 0 8	£195 14 11	*£16 10 3*	£1,685 9 4	£181 12 7

ACCUMULATED FUNDS

	£ s. d.	£ s. d.
Balance at 28th February, 1962		23,021 14 3
Add Transfer from Subscriptions Received		9 9 0
		£23,031 3 3
Less—		
Increase in Reserve for Bad Debts ..	46 8 6	
Transfer for Long Service Leave Fund Provision	25 0 0	
Transfer from Subscriptions Received..	3 3 0	
Deficit for Twelve Months	117 9 4	
		192 0 10
		£22,839 2 5

Auditors' Report

The above Balance Sheet has been prepared from the Books of Account, Accounts and Vouchers of the Royal Society of New South Wales, and is a correct statement of the position of the Society's affairs on 28th February, 1963, as disclosed thereby. We have satisfied ourselves that the Society's Commonwealth Bonds and Inscribed Stock are properly held and registered.

HORLEY & HORLEY,
Chartered Accountants,
Registered under the Public Accountants Registration Act 1945, as amended.

Prudential Building,
39 Martin Place, Sydney,
22nd March, 1963.

(Sgd.) C. L. ADAMSON,
Honorary Treasurer.

INCOME AND EXPENDITURE ACCOUNT

1st MARCH, 1962, to 28th FEBRUARY, 1963

1962				£ s. d.
4	Advertising			1 15 7
34	Annual Social			6 5 5
37	Audit			37 16 0
42	Branches of the Society			9 12 0
104	Cleaning			106 0 0
33	Depreciation			33 13 2
56	Electricity			65 17 6
3	Entertainment			4 2 0
38	Insurance			34 16 6
117	Library Purchases			132 16 3
152	Miscellaneous			157 6 6
123	Postages and Telegrams			169 4 4
	Printing—Journal—			
	Vol. 95, Parts 5–6	£510 10 6		
	Binding	32 1 3		
	Vol. 96, Part 1	137 15 6		
	Reprints	183 4 3		
	Postages	43 0 8		
	Provision for Vol. 96, Parts 2–6	1,000 0 0		
			1,906 12 2	
	Less—			
	Sale of Reprints	288 12 0		
	Subscriptions (to Journal)	330 17 4		
	Back Numbers	33 12 0		
	Refund Postages	18 15 4		
697			671 16 8	
				1,234 15 6
197	Printing—General			216 2 2
992	Rent—Science House Management			984 18 0
9	Repairs			5 15 8
1,402	Salaries			1,438 13 6
42	Telephone			37 13 2
£4,082				£4,677 3 3

1962		£ s. d.
935	Membership Subscriptions	956 0 6
7	Proportion of Life Members' Subscriptions	7 7 0
750	Government Subsidy	750 0 0
2,088	Science House Management—Share of Surplus	2,059 11 2
106	Interest on General Investments	108 12 8
—	Sale of Periodicals *ex* the Library	676 0 7
—	Donation	2 2 0
196	Deficit for twelve months	117 9 4
£4,082		£4,677 3 3

Obituary

Adolph Bolliger, Ph.D. (Basle), D.Sc. (Sydney), was born in Schmiedrued (Zurich), Switzerland, on 8th October, 1897. His father was a master baker. He qualified to enter the University of Zurich in the autumn of 1916 but was delayed by military service until the following summer. In 1918 he studied at the University of Geneva, saw more military service, and had a brief encounter with Lenin, then a political refugee in Zurich. In 1919, after a short period at Zurich, he entered the University of Basle and obtained his Doctorate of Philosophy (Magna cum Laude) in 1921. For the following two years he worked in the chemical dye and textile industry in Germany. In 1923 he emigrated to the United States which had long attracted Swiss citizens and where relatives were already established. His first work was in a factory but after a short time he obtained a position as a biochemist, specializing in cardiovascular disease in the Henry Ford Hospital, Detroit. In 1926, with two other colleagues, he was awarded the silver and gold medals of the American Medical Association for the best research work presented.

In 1928 Bolliger met the eminent Australian surgeon Gordon Craig, who invited him to take up a post in Sydney in the laboratories of the Royal Prince Alfred Hospital. In 1930 he was appointed Director of the Gordon Craig Research Laboratories in the Department of Surgery of Sydney University. In 1935 he became a naturalized Australian citizen and, in 1936, was awarded the Rennie Memorial Medal by the Australian Chemical Institute. Within the University of Sydney he was, in 1938, given the status of Lecturer, in 1949 of Senior Lecturer, and in 1955 of Reader. In 1957, on the presentation of his published works on chemical studies of integuments of vertebrates and observation on marsupials, he was awarded the degree of Doctor of Science. In 1933 he was elected to membership of the Royal Society of New South Wales, served for a number of years on its Council, was President in 1945–6, and in 1962 was awarded the Society's Medal (see *Journal*, v. 96, p. 171). In 1947 he was President of Section N of A.N.Z.A.A.S. at its Perth meeting. In that year also he was awarded the Henry G. Smith Medal.

Adolph Bolliger's published work covers a wide field and includes studies in analytical and organic chemistry, biochemistry, anatomy, physiology and experimental pathology. More recently he became interested in the micro-analysis of marsupial's milk. He had perfected a method of removing the tiny marsupial foetus from the maternal teat, extracting a drop of milk and then reapplying the foetus in such a way that further survival was possible. This study provoked considerable overseas interest, and it was suspected that it may well have a significant application to the management of human pre-maturity.

Bolliger's genial, generous personality invited friendship and those who found his hearty manner a trifle overwhelming and held aloof were the losers. He had a full and happy personal life. His main recreation was skiing. In 1937 he married Dorothy Dark, and after her death, Jocelyn Elliot, with both of whom he had been associated in research in the University.

By his death on 22nd October, 1962, Australia lost a notable adopted son who had contributed substantially to Australian science. He leaves five sons, of whom four are in Australia and one is an architect in Switzerland.

Anthony Dadour was elected to membership in 1940. He received the degree of Bachelor of Science from the University of Sydney in 1940 and was engaged in the chemical industry. He died suddenly on 18th August, 1962.

Francis Patrick Joseph Dwyer, D.Sc. (Sydney), Professor of Biological Inorganic Chemistry in the John Curtin School of Medical Research of the Australian National University, died suddenly on 22nd June, 1962, at his home in Canberra. He was born in 1911 at Nelson Plains, New South Wales, and was educated at the Marist Brothers' College, Maitland, and the University of Sydney, whence he graduated in 1932. He was recognized as a world authority in the field of inorganic chemistry, his recent work being concerned with the synthesis of metal-containing drugs and their uses in biology and medicine. His research in recent years led to the discovery of a potentially useful biologically active compound which has shown promise in the prevention and cure of a number of local infections.

Dwyer's versatility, and the breadth of his interests, are shown by more than 150 publications (62 in the Society's *Journal*) spread over the following topics: the chemistry of platinum, palladium, rhodium, iridium, ruthenium and osmium, isomerism of the triazines and diazoamino compounds and their metal derivatives, the redox potentials of simple compounds and complexes of the platinum series of metals, the optical activity and kinetics of substitution and racemization of Group 8 metal complexes, the diastereoisomeric effect and the principle of configurational activity, the stereochemistry of multidentate chelates, stereospecific influences in octahedral complexes, electron transfer reactions, the effects of metal complexes in biological systems, and X-ray analysis and micro-analytical reagents and procedures. For his work on diazoamino compounds their metallic hydroxide lakes and metallic salts he was awarded the degree of Doctor of Science of the University of Sydney, the Rennie Medal of the Royal Australian Chemical Institute (1940), and the H. G. Smith Medal in 1945. In 1953 the University of Melbourne awarded him the David Syme Medal and Prize for distinguished work in natural science.

From 1934 until 1945 Frank Dwyer was senior lecturer and head of the Department of Inorganic Chemistry in the Sydney Technical College. In 1946 he was appointed senior lecturer in Inorganic Chemistry

in the University of Sydney, was visiting professor at Northwestern University during 1953–54. In 1956 he was appointed to a new chair in inorganic chemistry in Pennsylvania State University but resigned in 1957 without taking up the post to become reader and head of the Biological Inorganic Chemistry Unit in the John Curtin School of Medical Research of the Australian National University. In 1960, on account of his outstanding contribution to inorganic chemistry, he was elected to one of the first personal professorships created in the Australian National University. He was elected a Fellow of the Australian Academy of Science in 1961. Shortly before he died he had given a series of lectures at the invitation of the American Chemical Society. He was elected to membership of the Royal Society of New South Wales in 1934 and served on the Council for a period in the 1940's.

Dwyer is remembered by many for his outstanding ability, personal charm, friendliness and modesty. Generations of former students will also remember his sense of humour, unfailing cheerfulness and enthusiasm.

Professor Dwyer is survived by his widow, two sons and a daughter.

George Francis (Frank) Leechman was born in England in 1898, received his education at Dunstable Grammar School and was apprenticed in the Merchant Navy in 1915. He saw considerable sea service during World War I, obtained his Master Mariner's Certificate in 1923 and settled ashore in Singapore, with his wife, in 1923. After his wife's death in 1931 he returned to England with his infant son and settled in Cornwall, where he became interested in gemstones and was the owner of a prosperous business. It was at this time that his interest in opals began.

During the second war Captain Leechman worked on diamond polishing for the British Government but after the war his keen interest in opals led him to come to Australia to further his knowledge of these stones ; the result was his book, " The Opal Book ", which is recognized as a standard work on the subject of opals.

During the last few years Captain Leechman had suffered ill health ; and after the tragic death of his only son with wife and child in a motor accident near Glen Innes in 1960 he never really recovered. The last year of his life was devoted to the production of a handbook for amateur gemmologists designed to teach them the art of grinding and polishing gemstones. He was elected to membership of the Royal Society of New South Wales in 1957. He died on 9th February, 1963.

Burnett Mander-Jones, B.Sc. (Hons.), M.Sc. (Sydney), Dip.Chem.Eng. (Lond.), A.R.A.C.I., member of the Royal Society of N.S.W. and Deputy Chief Analyst of the Mines Department of N.S.W., passed away on 12th July, 1962, at the age of 58 years.

He attended Sydney Church of England Grammar School (" Shore ") and Sydney University.

After serving as chemist in the Kandos Cement Works, N.S.W., and the Defence Department Laboratories at Maribyrnong, Victoria, he joined the Chemical Laboratory of the N.S.W. Mines Department in 1929, becoming second-in-charge in 1956.

He was a keen civilian soldier and had progressed from Gunner to Major in the Anti-Aircraft Artillery at the outbreak of the 1939–45 war, when he immediately enlisted for active service, was promoted to Lieutenant-Colonel, seeing the whole six years' war service.

At the end of the war he proceeded to England (under Commonwealth Grant) and obtained the Diploma in Chemical Engineering of London University.

He was an original member of the old Scientific Officers' Sub-Section, and later Councillor of the Professional Section of the Public Service Association of New South Wales for many years until his death. He was elected to membership of the Royal Society of New South Wales in 1960 and had one paper published in the Society's *Journal*.

He came of a well-known, respected and talented family. His father was a doctor ; both his brothers were Lieutenant-Colonels, one won the Sword of Honour at Duntroon and served on the N.W. frontier of India before the war, the other, who was on General Blamey's (C.I.C.) staff, is now Director of Education in South Australia ; his sister, Miss P. Mander-Jones, was Mitchell Librarian before her retirement. He rowed in his college eight at the University, played vigorous hockey in the early 'thirties, and was interested in fencing and pistol shooting.

A kindly, sincere, courteous and generous gentleman, but a stickler for the rights of his fellows ; our sincere sympathy is extended to his wife, his brothers and his sisters.

Members of the Society Elected During 1962

BADHAM, Charles David, M.B., B.S., D.R. (Syd.), M.C.R.A., 16 Ormonde Parade, Hurstville.

BAKER, William Ernest, B.Sc. (Hons.), Geologist, 394 Kaolin Street, Broken Hill, N.S.W.

BRENNAN, Edward, B.E. (App. Geology), 94 Parbury Road, Swansea, N.S.W.

DANCE, Ian Gordon, B.Sc. (Hons.), Analytical Chemist, 22 The Promenade, Cheltenham.

DRAKE, Rev. Lawrence Arthur, B.A. (Hons.), B.Sc., Canisius College, 102 Mona Vale Road, Pymble.

FINDLER, Nicholas Victor, B.E. (Hons.), Ph.D., Applied Mathematician, c/o C.S.R. Co. Ltd., O'Connell Street, Sydney.

FISHER, Stephen, M.D., B.Sc., Director of Clinical Pathology, Kanematsu Memorial Institute, Sydney Hospital.

GORDIJEW, Gurij, Institute Hydro Meteorology in Moscow, Faculty of Hydrology, Graduated Engineer Hydrogeology (1936), 41 Abbotsford Road, Homebush.

LEWIS, Philip Ronald, J.P., Design Engineer, 13 River View Road, Woolooware.

MACKAY, Robin Marie, B.Sc., Department of Geology and Geophysics, The University of Sydney, Sydney.

NEWMAN, Thomas Montagu, Hotel Acton, Canberra, A.C.T.

READ, Harold Walter, B.Sc., 1 Karog Street, Blacksmiths, 2N, N.S.W.

SMITH, Glennie Forbes, B.Sc., Geologist, c/o Mine Department, Mt. Lyell Mining and Railway Co. Ltd., Queenstown, Tasmania.

THWAITE, E. G., B.Sc., 8 Allars Street, West Ryde.

YATES, Harold, M.Sc. (Syd.), 102 Eyre Street, Ballarat, Victoria.

Medals, Memorial Lectureships and Prizes

Clarke Medal

1963 Germaine Anne Joplin, B.A., D.Sc. (Syd.), Ph.D. (Cantab.)

The Society's Medal

1962 Harley Wood, M.Sc. (Syd.)

Walter Burfitt Prize

1962 Martin Fritz Glaessner, Ph.D., Dr.Jur. (Vienna), D.Sc. (Melb.)

Edgeworth David Medal

1962 Raymond Frederick Isbell, M.Sc. (Qld.)

Recipients of Society Awards, 1963

Germaine Anne Joplin, Senior Fellow in the Department of Geophysics, Australian National University—the Clarke Medal.

The Clarke Medal for 1962 is awarded to Dr. Germaine A. Joplin, B.A., Ph.D., D.Sc., for her distinguished contributions to Geology, particularly in the field of igneous and metamorphic petrology.

She graduated in Science at the University of Sydney in 1930, and has devoted most of her time since then to geological research. She was a Macleay Fellow in Geology of the Linnean Society of N.S.W. from 1941 to 1944, and has carried out research at the University of Sydney, the University of Cambridge, the Bureau of Mineral Resources at Canberra, and more recently at the Australian National University. Her geological interests have taken her to Great Britain, Europe, Canada and U.S.A. She holds the degrees of Ph.D. (Cantab.) and D.Sc. (Syd.).

Dr. Joplin lectured at the University of Sydney from 1936 to 1940, and from 1945 to 1949. Both at Sydney and as Research Fellow at A.N.U., where she has supervised the work of graduate students in petrology, she has always been most generous in her assistance and encouragement to younger geologists. Her published work consists of about 40 papers, mainly dealing with the geology and petrology of special areas of eastern Australia, which form the basis of notable contributions to petrological thought, particularly in regard to magmatic differentiation, granitization and metamorphism.

Dr. Joplin's compilation of all known chemical analyses of Australian rocks is being published by the Bureau of Mineral Resources, and at present she is writing a Textbook of Petrology, based on her wide knowledge of Australian rocks.

Harley W. Wood, Government Astronomer, Sydney Observatory—the Society's Medal.

Mr. Wood's contribution to the Society has been rarely surpassed by any member past or present. He has been a member of Council for the years 1943–47, 1950, 1953, 1956–61; Hon. Secretary 1948, 1951, 1958–60; Hon. Librarian 1943–47, 1957; and was President in 1949.

Mr. Wood joined the Society in 1936 and has been an active member since that date. Apart from the positions held on Council he has acted on a large number of committees.

Since he became Government Astronomer in 1944, Mr. Wood and his group have contributed extensively to the Society's "Journal". This group has undertaken the immense task of mapping a large part of the Southern skies, a task which is never ending.

One of the simplest duties in Mr. Wood's eyes but one of the most important in the progress of a large city is the determination of time. Mr. Wood is responsible for the accuracy of our time signals.

Mr. Wood has for many years been one of the leading publicists for science both in the serious and the popular field. This is evidenced by the long booking list to visit our Observatory. Since the advent of artificial satellites and the commencement of investigation into such close outer space phenomena, the value of Mr. Wood's work in the popular educational field has increased markedly. He has done much to correct the nonsense published in science fiction and the newspapers.

The Society recognizes that Mr. Wood is one of our most widely known and respected scientists and wishes him success in his future efforts at the Observatory.

Martin Fritz Glaessner, Reader in Geology and Palaeontology in the University of Adelaide—the Walter Burfitt Prize.

The Walter Burfitt Prize for 1962 is awarded to Dr. Martin F. Glaessner, D.Sc., F.A.A., for his work published during the last six years on problems of Palaeontology, particularly his contributions to the knowledge of Pre-Cambrian fossils of South Australia; Tertiary stratigraphic correlation in the Indo-Pacific Region and Australia; and evolutionary trends in some Protozoa and Arthropoda.

Dr. Glaessner graduated in Palaeontology at the University of Vienna, and has done research work at the British Museum (Natural History). From 1932 to 1937 he took part in several geological expeditions to the Caucasus as Foreign Specialist (Palaeontologist) for the U.S.S.R. Academy of Sciences.

In 1938 he joined the Anglo-Iranian Oil Company and in New Guinea established a laboratory for research in micro-palaeontology, which was later transferred to Melbourne. Here he did graduate work at the University and obtained the degree of Doctor of Science.

He joined the staff of the University of Adelaide in 1950. In 1953 he was made a Research Associate of the American Museum of Natural History, and in 1956 was elected a Fellow of the Australian Academy of Science.

Dr. Glaessner has an international reputation as a palaeontologist and stratigrapher and his researches have been published in scientific journals in most countries of Europe and Asia, and also in U.S.A. and Australia.

Dr. Glaessner was the Clarke Memorial Lecturer of this Society in 1953.

Raymond Frederick Isbell, Research Officer, C.S.I.R.O. Division of Soils, Queensland—the Edgeworth David Medal.

Raymond F. Isbell graduated from the University of Queensland with distinction in geology in 1950 and in 1953 received his M.Sc.

A man's capacity for research may be measured by his ability to adapt himself to other fields of study when he passes on from his academic training. Isbell showed just such versatility and initiative to cope with many phases of field study, ecological, pedological and practical problems of land utilization aside from geology. At an early stage he turned his attention

to geographical studies in valuing land resources and, as an officer of the Queensland Bureau of Investigation, covered a number of areas in central and sub-coastal regions in that State. His academic training stood him in good stead due to the correlation of geological structures to the land forms and the soils associated with them. Over a period of ten years Isbell has devoted himself to the study of economic resources in the underdeveloped areas of Queensland, mainly of those with a rainfall less than 30 inches.

The culminating and most recent work for which he will long be noted is the survey of nearly 40,000 square miles in Central and Southern Queensland and Northern New South Wales comprising the " Brigalow Belt " characterised by growth in varying density of *Acacia harpophylla*. Approximately half this great zone stretching 700 miles from north to south and 50 miles wide, is covered by brigalow scrub. Isbell has recorded and analysed its soils, flora, climatology, grazing and crop potential and defined the problems in development. The notable publication of these data has been used by economists and others concerned with land use in Queensland. Since the native vegetation is fast disappearing in the face of agricultural and pastoral advances, his work on the ecology and details of flora associated with this great belt of country will be a classic reference.

Mr. Isbell has continued his interest throughout in geological studies. He, with collaborators, was responsible for chapters in the volume on the geology of Queensland published by the Geological Society of Australia in 1960.

His record of publications beginning in 1954 contains three technical bulletins on the soil and land resources of parts of Queensland, the long publication mentioned on the "Brigalow Belt", three geological papers, two pedological papers and one ecological contribution. All of these involved field observations extensively over the years and together have given a mass of valuable data of particular use in these days of rapid development of Queensland.

Abstract of Proceedings, 1962

4th April, 1962

The ninety-fifth Annual and seven hundred and seventy-third General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor R. J. W. Le Fevre, F.R.S., F.A.A., was in the chair. One hundred members and visitors were present.

Nicholas Victor Findler and Gurij Gordijew were elected members of the Society.

The Annual Report of the Council and the Financial Statement were presented and adopted.

The following awards of the Society were announced :

The Society's Medal for 1961 : Dr. A. Bolliger.
The Clarke Memorial Medal for 1962 : Professor H. Waring, D.Sc., F.A.A.
The James Cook Medal for 1961 : Sir John Eccles, Kt., D.Phil., F.R.S., F.A.A.
The Edgeworth David Medal for 1961 : Dr. R. L. Slatyer.
The Archibald D. Ollé Prize : Professor V. A. Bailey, D.Phil., F.A.A.

Office-bearers for 1962–63 were elected as follows :
President : W. B. Smith-White, M.A.
Vice-Presidents : H. A. J. Donegan, M.Sc., A. F. A. Harper, M.Sc., R. J. W. Le Fevre, D.Sc., F.R.S., F.A.A., W. H. G. Poggendorff, B.Sc.Agr.
Hon. Secretaries : J. L. Griffith, B.A., M.Sc., Alan A. Day, B.Sc., Ph.D.
Hon. Treasurer : C. L. Adamson, B.Sc.
Members of Council : Ida A. Browne, D.Sc., A. G. Fynn, B.Sc., N. A. Gibson, Ph.D., J. W. Humphries, B.Sc., A. H. Low, Ph.D., M.Sc., H. H. G. McKern, M.Sc., P. D. F. Murray, D.Sc., F.A.A., G. H. Slade, B.Sc., A. Ungar, Dipl.Ing.

Messrs. Horley & Horley were re-elected as Auditors of the Society for 1962–63.

The retiring President, Professor R. J. W. Le Fevre, F.R.S., F.A.A., delivered his Presidential Address entitled " Some Chemical and Scientific Problems of the Late Twentieth Century ".

Reference was made to some of the problems which are, or soon may be, confronting science and scientists.

Studies of molecular architecture in relation to properties should increasingly enable chemistry to meet new challenges (e.g., high-speed flight or space exploration) or continuing ones (e.g., disease), and to understand vital processes (e.g., inheritance or the origination of life on this planet). Such particular matters can be viewed with optimism.

Considered more widely, however, the outlook for science is pessimistic. Progress is already being handicapped by certain genetic problems (" training ", recording and accessibility of information, political and social attitudes, etc.), but these pale before the difficulties (international, technological, personal, and ethical) foreseeable from the massive expansion of mankind now occurring. (Each year is adding population equivalent to 22 Cities of Sydney.) All human effort is overshadowed by the apparent predictability from present evidence of a not distant " doomsday " (one group gives the date as 13th November, 2026). The balance of nature has been upset. The challenge has an inexorable quality, yet is more neglected by governments than any other of the major factors in the world crisis. Consequences are obvious : can they be mitigated or avoided ?

At the conclusion of the meeting the retiring President welcomed Associate Professor W. B. Smith-White to the Presidential Chair.

2nd May, 1962

The seven hundred and seventy-fourth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Associate Professor W. B. Smith-White, was in the chair. There were present 22 members and visitors.

Eric Graham Thwaite was elected a member of the Society.

It was announced that Mr. H. G. Golding had been appointed a member of the Council, Dr. B. A. Bolt having resigned.

An address entitled " The Employment of Women in Australia " was delivered by Mrs. Thelma Hunter, M.A. (Glasgow), of the Department of Government, University of Sydney.

It is generally assumed that the participation of women in economic activity has substantially increased over the past half century. To what extent is this so ? And what are the major changes which have taken place in the distribution and characteristics of the female work force ? The speaker considered some of the legal institutional and conventional factors which affect the employment of women in industry. Finally, she gave an analysis of the principles applied by Australian industrial tribunals in determining the female basic wage. What effect does this have on the application of equal pay rates ? And to what extent does the 1958 New South Wales legislation on equal pay affect the Court's principles of wage determination ?

6th June, 1962

The seven hundred and seventy-fifth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Associate Professor W. B. Smith-White, was in the chair. Ninety members and visitors were present.

Ian Gordon Dance was elected a member of the Society.

It was announced that the newly elected officers of the Section of Geology were : Mrs. K. M. Sherrard (Chairman) and Mr. H. G. Golding (Honorary Secretary).

An address dealing with the Scientific Investigation of Crime was delivered by Detective Sergeant N. A. Merchant, of the Scientific Investigation Bureau, New South Wales Police Department.

4th July, 1962

The seven hundred and seventy-sixth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Associate Professor W. B. Smith-White, was in the chair. Fifty-five members and visitors were present.

Glennie Forbes Smith was elected a member of the Society.

An address entitled " On Some Problems of Artificial Intelligence " was delivered by Dr. N. V. Findler, of the Colonial Sugar Refining Co. Ltd., Sydney.

One of the most powerful stimuli to progress in scientific research is the bringing together of two ostensibly widely differing fields of endeavour. An example for this event is the challenging combination of research efforts from the disciples of psychology and computer science.

The lecture will attempt to describe the motives and the methodology of a few works with digital computers in this field. Theoretical and practical applications cover a wide area, ranging from mechanized medical diagnosis to computer-composed music. With the advent of faster, bigger and more powerful machines the successful simulation of certain highly organized mental activities of humans has become a problem of ingenious programming rather than representing some insurmountable technological difficulty or a question unsolvable in principle.

1st August, 1962

The seven hundred and seventy-seventh General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Associate Professor W. B. Smith-White, was in the chair. Forty-five members and visitors were present.

Stephen Fisher, Robin Marie Mackay, Thomas Montagu Newman, Harold Walter Read and Harold Yates were elected members of the Society.

The Edgeworth David Medal for 1961 was presented to Dr. R. O. Slatyer, C.S.I.R.O., Division of Land Research and Regional Survey, Canberra, and following the presentation Dr. Slatyer delivered an address entitled " Some Aspects of Water Use ".

5th September, 1962

The seven hundred and seventy-eighth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The Senior Vice-President, Professor R. J. W. Le Fevre, F.R.S., F.A.A., was in the chair. Eighty-five members and visitors were present.

Charles David Badham and Lawrence Arthur Drake were elected members of the Society.

An address entitled " The Sydney Opera House " was delivered by Mr. G. Molnar, Faculty of Architecture, University of Sydney.

3rd October, 1962

The seven hundred and seventy-ninth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Associate Professor W. B. Smith-White, was in the chair. Fifty-four members and visitors were present.

Edward Brennan was elected a member of the Society.

An address entitled " The Search for Oil in Australia : A Progress Report " was delivered by Mr. J. C. Cameron, School of Mining Engineering and Applied Geology, University of New South Wales.

7th November, 1962

The seven hundred and eightieth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Associate Professor W. B. Smith-White, was in the chair. There were present forty-three members and visitors.

The following were elected members of the Society : William Ernest Baker and Philip Ronald Lewis.

The following papers were presented : " Geology of Lord Howe Island ", by J. C. Standard ; " The Volatile Oil of the Genus *Eucalyptus* (Fam. Myrtaceae). 1. Factors Affecting the Problem ", by J. L. Willis, H. H. G. McKern and R. O. Hellyer.

5th December, 1962

The seven hundred and eighty-first General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The senior Vice-President, Prof. R. J. W. Le Fevre, F.R.S., F.A.A., was in the chair. There were present fifty-nine members and visitors.

An address entitled " Lawrence Hargrave—An Appreciation ", was delivered by Mr. W. Hudson Shaw, Assistant Administration Manager (G.S.), QANTAS, Sydney.

A few years ago Mr. Shaw endeavoured to obtain some information in Sydney on the famous Australian inventor, without success.

Shortly afterwards the author went overseas and during a prolonged stay found time to carry out valuable research in the U.S.A., England and Germany into Hargrave's life and work. The results were recorded and given to the major Aeronautical Collections of the world located in London, Washington and Munich.

Lawrence Hargrave was a prominent member of this Society for many years and the results of his experiments were made available to experimenters in other parts of the world largely through papers published in the " Journal and Proceedings ".

It is appropriate, therefore, that the first public presentation of the results of this research should be given to the Royal Society of New South Wales.

The lecture was illustrated with lantern slides, and original models made available by courtesy of the Trustees of the Museum of Applied Arts and Sciences.

See " Journal and Proceedings ", Vol. 96, *p.* 17.

Section of Geology

Chairman: Mrs. K. M. Sherrard, M.Sc.; Hon. Secretary: H. G. Golding, M.Sc.

Abstract of Proceedings, 1962

Five meetings were held during the year, the average attendance being 17 members and visitors.

MARCH 16*th* (Annual Meeting). The election of office-bearers was postponed to the next meeting due to poor attendance.

(1) Notes and Exhibits: Mr. H. G. Golding exhibited specimens of rodingite and rodingite-chromitite associations from the Mt. Lightning district in the Coolac-Goobarragandra serpentine belt.

(2) Address: " Lantern slides to illustrate a new course— The Nature of Geological Thought ", by Dr. L. E. Koch. Dr. Koch showed coloured slides of localities mainly from the Sydney metropolitan area, from New South Wales and other parts of Australia, illustrating landforms, rock types, structures and fossils to illustrate the new course.

MAY 18*th*: Election of office-bearers for 1962: Mrs. K. M. Sherrard was elected Honorary President and Mr. H. G. Golding was re-elected Honorary Secretary of the Section.

(1) Notes and Exhibits: Mr. H. G. Golding exhibited specimens of chromitite with ellipsoidal serpentinite structures, from Keef's Mine, Honeysuckle Range, N.S.W. Similar types had been recorded from overseas and according to Thayer were limited to Alpine type serpentinites.

(2) Address: " Aspects of the Geology of Mull and Skye ", by Dr. T. G. Vallance. At Mull basic igneous sheets intruding mainly Mesozoic and Tertiary country rocks resulted in local hornfelses containing mullite and sapphire. Specimens from the contact of the Rudh, a Chromain tholeiite sill, near Carsaig, were exhibited. At Skye the Tertiary Beinn an Dubhaich granite, south of Broadford, invades Cambrian dolomites and limestones. Here boron and fluorine, from the granite were fixed in the hornfelses and dedolomitization occurred in the inner contact zone with redistribution of Mg in the cooler outer zone. Magnetite skarns, grossular-wollastonite and hedenbergite-plagioclase assemblages and monticellite-bearing rocks occur. Fluorine is fixed in the contact zones mainly as clinohumite, cuspidine and fluorite; boron mainly as szaibelyite, datolite, ludwigite, and a new isometric mineral harkerite. Fluoborite represents fixed fluorine and boron. Specimens illustrating these hornfels types described by Tilley (*Mineralogical Magazine*, 1951) were exhibited by Dr. Vallance.

JULY 20*th*: The meeting paid tribute by a short silence to Professor D. W. Phillips and to Mr. A. J. Shearsby, both of whom had died since the last meeting.

Address: " Radio-active Haloes ", by Professor Paul Ramdohr. Radio-active inclusions in rocks and minerals result in surrounding haloes. The radiation may wholly or partly destroy either the inclusion or host, and the increase in volume of the resulting product can cause radiation cracks or " blasting " ranging from a few microns to two metres diameter in the host. Haloes correspond with the radii reached by the various types of alpha particles (e.g. of U, Ra, RaA) in the various mineral media, approximately 1/2000th of the radii in oxygen. Haloes have been noted in about fifty different mineral species. The former explanation for these phenomena—of local de-ionization in ionic-bonded minerals—is inadequate because haloes also occur in minerals with essentially covalent, metallic and molecular bonding (e.g. ilmenite, columbite, arsenopyrite, graphite and coal). Very strong radiation destroys haloes and facilitates special forms of early replacement, e.g. microcline by pyrite. By heating, so-called metamict minerals may be reconstituted with release of much stored energy. Professor Ramdohr illustrated his address by numerous slides.

SEPTEMBER 21*st*: (1) Notes and Exhibits: Miss H. Drummond exhibited a series of rocks from the Cape Dan area, near the airstrip of the American Radar Station " Project Due E " on the coast of East Greenland. Coastal rocks along most of this area appear to be volcanic but those exhibited from this locality included acid garnet-rich gneissic rocks, pegmatites and more basic types, distinct from the fine-grained more recent flows. Miss Drummond also showed transparencies of the Cape Dan and nearby coastal area of East Greenland. Messrs. H. G. Golding and M. Veeraburus jointly noted the occurrence of a spilite-chert-tuff-greywacke assemblage on the western flanks of the Coolac serpentine belt, New South Wales. Specimens of spilite from near Brungle and of red chert and amygdaloidal lava from Mt. Lightning were exhibited.

(2) Address: " Aspects of the Geology of Thailand ", by Mr. M. Veeraburus. The Kohart Plateau of Thailand is regarded as a stable nucleus surrounded by the Japanese, Philippines, Indonesian and Himalayan arcs and the Malayan-Sarawak-Borneo Mountain Chains. Two major revolutions accompanied by granite intrusion—the permo-Triassic or older granite and the late Cretaceous, early Tertiary or Younger granite—are recognized. The stratigraphic column includes representatives of all the main geologic systems other than Pre-Cambrian and Cretaceous. The Upper Cambrian Phuket Series and Taroo Tao Series containing Eophytons and Saukid trilobites respectively is followed disconformably by the Ordovician Tungsong Limestone of the Peninsular-Perlis Region. The widespread undifferentiated Kanchanaburi Series includes Silurian, Devonian and Carboniferous rocks lying unconformably on the aforementioned. The Rat Buri Limestone is Permian but in places undifferentiated beds are referred to the " Permo-Carboniferous ". The Triassic-Jurassic Khorat Series was followed by Tertiary sedimentation, representatives of which include lignite, oil-shale and some oil-reservoir rocks. Pleistocene deposits are widespread. Mr. Veeraburus illustrated his address with colour transparencies.

NOVEMBER 16*th :* (1) Notes and Exhibits: Professor L. J. Lawrence reported on a solid state reaction between cassiterite and bornite in ore from near Inverell, N.S.W. Hexastannite reaction rims are associated with renierite and suggest grain boundary ex-solution of the latter from the Hexastannite.

(2) Address: "Granitization Phenomena in the Jesenik Mountains in the Bohemian Massif", by Dr. Z. Misar. Various zones of metasomatic granitization have been distinguished in the Keprnik Dome in the Jesenik Mountains, in the northern part of the Bohemian Massif. Granite gneisses of the central part of the dome represent a centre of microcline granitization and contain large porphyroblasts of microcline up to 5 cm. in diameter. Relict streaks of biotite gneisses and inclusions of calc-silicate rock are common. In the second or augen-gneiss zone porphyroblasts of microcline as augen average 1–3 cm. in diameter. The third or "pearl-gneiss" zone contains smaller microcline porphyroblasts (0·3–0·1 cm. diameter), and is surrounded by the non-granitized or primary zone of biotite-plagioclase gneisses. It seems that at a certain stage of geosynclinal development so-called permanent elevations and depressions were formed. The elevations became the centres of granitization while the depressions became centres of submarine vulcanism and exhibit a complete lack of granitization phenomena. The age of these processes is probably Pre-Cambrian. Dr. Misar accompanied his address with colour slides.

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Positional Astronomy

The Donovan Astronomical Lecture for 1963*

Harley Wood
Sydney Observatory, Sydney

Abstract—The aims and methods of positional astronomy are outlined and the contribution of Sydney Observatory briefly described. Future developments, particularly in the southern hemisphere, are discussed

I appreciate the invitation to give the Donovan Astronomical Lecture for 1963 because it gives me an opportunity to speak about the field of astronomy in which our Observatory at Sydney is working. Early in this century Simon Newcomb (1906) was able to say " the determination of positions of the fixed stars by meridian observations has formed a large fraction of the work of the leading observatories since 1750 ". Every positional astronomer rejoices that astronomy has enormously extended its bounds so that his work is now only a small fraction of the total of astronomical effort, but I have heard complaints from some of them that, despite a demand for the results of positional astronomy, it is nevertheless difficult to obtain resources and prestige for positional work. This may well be because the newer developments in astrophysics, radioastronomy and space science with their spectacular methods and results, have such public appeal that it is easier to obtain support for them. Some people, even among scientists, appear to feel that positional astronomy which has been active for so long, must be a worked out field and that appreciable improvements can be effected only with long delay or disproportionate effort. This is not so, for although unexpected spectacular results are not likely, it is clear that the application of developing techniques can yield an increase in accuracy which would be of much value in the reasonably near future.

Positional astronomy works fundamentally towards the establishment of a coordinate system, a "fixed" non-rotating system, to which all positions in the heavens may be referred. Catalogues of stars are compiled with positions referred as accurately as possible to the system, and by comparing positions at different epochs the motions of the stars across the sky are evaluated and catalogued. This is done by a variety of methods appropriate to the objective, whether it may be to compile a catalogue of stars over the whole sky, or over a restricted zone or within a limited area of particular interest. On the other hand the position of isolated objects, such as members of the solar system may be sought or, possibly most exacting of all, the aim might be the determination of the distance of a star.

A fundamental part is played by positional astronomy in many general activities of astronomy and astrophysics. Firstly a framework is provided for the identification of objects, for an accurately known position is the most unambiguous, and, properly used, the surest way of specifying and finding a particular one of any class. There are about 10^8 stars to magnitude 17 and 10^6 galaxies to magnitude 18 with many more accessible to observation by large instruments. However, there are $1 \cdot 5 \times 10^8$ square minutes of arc in the sky so that, if a position is known with an accuracy of a second or two of arc, there can rarely be ambiguity. In some branches of astronomy insufficient attention is given to the positions which may be quoted to too few figures and even these may be in error. One frequently hears of telescope time being lost in the identification of objects and of the necessity for having finding charts for them. The solution is the development of a position-minded attitude, for these problems would be greatly diminished if positions were accurately given and if it were insisted that telescopes should be made to point with precision. This should not be too difficult, and in an expensive piece of apparatus like a large telescope there is no reason why, with present facilities for digital and analogue computation, the pointing should not include allowance for refraction and, if necessary, corrections for flexure. Secondly, positional astronomy provides the framework for deter-

* Delivered in Science House, Sydney, on 8th October, 1963.

A

mination of positions which are needed in celestial mechanics. This includes observations of artificial satellites. Thirdly, positional techniques, through proper motions, provide a sieve for the recognition of objects of various classes. Faint nearby objects are indicated by their large proper motions, and stars which belong to clusters or associations are sorted from field stars by community of motion. This process works even if the proper motion is expected to be negligible as in the case of the Magellanic Clouds (Royal Observatory Bulletins, 1963) for the foreground stars may be sorted out by their appreciable motion. Fourthly, statistical studies of proper motions, combined if possible with radial velocities, yield mean parallaxes for certain classes of stars. Hence the motions, by serving to calibrate the zero points for absolute magnitudes of the stars used as distance indicators provide a basis for distance measurement by luminosity methods. Fifthly, proper motions form part of the data for the study of galactic kinematics. In this category come researches which aim at improved values of the constants of galactic rotation and attempts to measure the expansion of associations of stars.

The Coordinate System

In order to specify position it is necessary to devise a system of coordinates. If these are to be satisfactory, they must conform to convenience for the purpose for which they are to be used, and their definition should be operational in the sense that a way of making actual measurement of the coordinates is implied. Since it is direction only that is to be specified in three-dimensional space, the system is two-dimensional. There are in the heavens no fixed points to which reference may be made since the stars in space are free to move in any direction and finally the whole problem is conditioned by the fact that we, and the instruments with which we observe, are situated on a rotating Earth. This last point means, on the one hand, that the coordinate system, if it is to be convenient in use, must be related to the Earth's rotation so that it will be easy to point earth-based instruments in a desired direction and, on the other hand, it means that we are provided with a way of scanning large areas of sky with instruments which have limited and stable degrees of freedom relative to their foundation.

To establish a two-dimensional system we need first to be able to identify accurately and with stability at least two points in the sky, or, of course, their equivalent a great circle and a point. One available point is the celestial pole about which the heavens appear at any instant to be revolving. It is therefore accessible to observation. The identification of the pole of the heavens leads to the establishment of the Equator as the great circle from which one coordinate, declination, is measured, and it then remains to choose some point on this as the origin for the measurement of the other, right ascension. The point which has been chosen is the equinox, the intersection of the equator and the ecliptic. It is accessible to observation, although not very readily, because the ecliptic is found from motions in the solar system, observation of which is therefore a necessary part of the programme to define the coordinate system. Some decision has to be made, and as good a compromise as possible is made by the choice of this point from which right ascensions are then measured towards the east.

The definitions implied by referring positions to the equator and its point of intersection with the ecliptic are affected by the fact that both the equator and the ecliptic are in motion relative to the background of the stars and in fact must be so relative to any standard of non-rotation which is likely to be suggested. The need for operational definition for both measurement and use of the coordinates requiring relation to identifiable points or planes of the sky is satisfied if the position of any body is referred to the equator and equinox of the time of the observation. Positions measured directly in accord with the definition are called apparent places. These are basic.

Because of the need to have a common framework for the comparison of positions observed at different times it is necessary to investigate the motions of the fundamental planes so that the positions may be referred to the coordinates based on the equator and equinox of some selected time. Since the direction from which the light of a star appears to arrive is also varied by the motion of the Earth, the effect of this, aberration, must also be removed. Positions dealt with in this way are called mean places. They are convenient, not only for comparing positions observed at different times for determination of stellar motions, or for investigations in celestial mechanics, but also as a base from which apparent places required for observation at all other times may be computed. It is always as mean places that positions of stars appear in catalogues. They are, however, less basic because they depend on the adopted values of

the constants which describe the motions of the fundamental planes, which are also derived from the observations.

Instruments

The description of the coordinates of astronomy is made more real by an account of the instruments with which they may actually be measured. The classical instrument of positional astronomy is the transit circle, but, since it has been described many times (e.g. Watts, 1960), my account must be brief. Its axis, supported on two fixed piers, is designed to be horizontal and running accurately east and west. The eye-end of the telescope is provided with a micrometer having spider lines which may be set on stars or on artificial objects for testing and calibrating errors of the instrument. The line of sight of the instrument determined by the spider lines in some standard position is designed to be perpendicular to the axis. In this ideal condition the instrument would thus trace the plane, including the directions of the pole and the zenith, of the meridian of its location. There is another axis of this instrument, the axis of the Earth, which by its rotation causes the meridian plane to scan the whole of the heavens accessible at the place in the course of a sidereal day. If an accurate clock is used to obtain the time when a star is on the meridian its position in right ascension may be interpolated relative to any right ascensions which, like that of the Sun, can be obtained from first principles if the declination is known. To the axis of the instrument is fitted an accurately divided circle which by reference to the reading for the zenith is used for measuring, for the determination of declination, the altitudes at which the stars cross the meridian.

Adjustment and maintenance of the transit circle in the desired state with sufficient accuracy is impossible, and so it is necessary to measure the deviations from the ideal so that the necessary corrections to the direct readings may be computed. The failure of the line of sight of the telescope to be perpendicular to its axis of rotation, the error of collimation, is a geometric condition of the instrument itself, and its magnitude may be found without reference to anything external except some auxiliary apparatus provided for the purpose. The departure of the axis from the horizontal has to be measured with reference to the gravitational vector. This may be found accurately because it is perpendicular to a free liquid surface from which a ray of light is reflected according to the law of reflection. The nadir, or the zenith, is so continuously and accurately accessible that it is used as a reference point in all instruments for direct determination of celestial positions but because of the dependence of its position on time and on the place of the observer it is necessarily only an auxiliary point and not a fundamental one. The positions of the celestial pole, including determination of the direction of the axis of the transit instrument, can be found only from astronomical observations, usually of stars near the celestial pole. These cross the meridian at upper and lower culminations at equal intervals of time and at equal distances above and below the pole, thus identifying its direction and altitude. With appropriate corrections for handicaps provided by nature, such as refraction, or by man, such as non-circulatory of pivots or errors of circle divisions, the time of transit of the star leads to right ascension and the circle reading to the declination.

Another instrument which is now making a contribution is the impersonal prismatic astrolabe, which has been described by Danjon (1958, 1960), who is responsible for its development. By simultaneous observation of the images of a star direct from the sky and as reflected in a mercury bath the time is found when the star reaches a fixed altitude which is actually near 60°. The altitude is established by the angle of the prism which makes parallel the rays from the two directions. It will be seen that the use of the bath of mercury fixes the relation with the zenith, and, when the instrument is rotated around its axis, the fixed altitude describes a small circle around the zenith. The rotation of the Earth permits the small circle to scan a zone 60° wide in declination. This instrument was designed for observation of longitude and latitude, including the variation of latitude arising from movement of the pole of the Earth's rotation relative to the body of the Earth. The places of the stars observed may be improved by adjusting them so that consistent values are given for the terrestrial position of the observer. The effectiveness of this instrument is due to the fact that it relies on the geometric stability of only one component, the prism, which determines the altitude at which the star is observed, and this component has proved very stable.

The photographic zenith tube, which was also designed for geodetic operations, can make contribution to the accuracy of catalogued star places. In this instrument the lens is arranged above a bath of mercury so that the image of

the star falls on a photographic plate situated just below the lens. The image plane contains the second nodal point of the lens which ensures that small tilting of the lens and photographic plate about a horizontal axis during the operations has no influence on the position of the star image on the plate. The reflection in the mercury bath refers these observations to the zenith, and the meridian is identified as perpendicular to the direction of the diurnal motion of the star. This instrument therefore scans a narrow zone of declination around all right ascensions and it is suitable for finding the errors which are functions of right ascension in the positions of stars which are accessible to it.

Fundamental Corrections

The observations are fundamental if they provide for the derivation of the position of the equator among the stars and the position of its intersection with the ecliptic, the zero point for the measurement of right ascension. The derived positions can then be made independent of previous catalogues. The right ascension system through its connection with the ecliptic, is defined by the motion of the Sun, observation of the declination of which, in principle, gives a correction to its right ascension. The fact that the planets move about the Sun in orbits which, with due allowance for perturbations, are plane and contain the Sun makes them also suitable for this purpose. The Sun and the classical planets differ in telescopic appearance from the stars, and systematic differences in observations of positions of the different classes of objects would be expected. For this reason the use of asteroids, which are stellar in appearance, was suggested for observations needed for the definition of the system of fundamental catalogues. These methods rely on Newtonian mechanics, by which the planets are taken to move, to provide a standard of rest for the coordinate system.

Selected minor planets have been included in programmes for this purpose. The observational programme and the solution of the equations of condition which provide for the corrections to the orbits of the planets, including the Earth, corrections to the system of the catalogue to which the positions are referred and corrections to some coefficients used in the position reductions make a formidable task. There are 164 unknowns in a scheme of Brouwer (1935).

For determination of the constant of precession some standard of non-rotation has to be assumed. Up to the beginning of this century it was taken that the general mean direction of the stars remained unchanged. Then with recognition of the real systematic motions of the stars as members of the Galaxy terms for the evaluation of these had to be added to the solution, or the assumption modified. For example, the assumption could be that there is no rotational motion in a direction perpendicular to the galactic plane or that the velocity component perpendicular to the galactic plane is on the average independent of galactic longitude (J. Schilt, 1960).

The background of the distant galaxies has been suggested as a standard of non-rotation and two programmes are in progress to determine accurately the stellar proper motions with reference to galaxies to obtain values of some fundamental constants, particularly the constant of precession. The 20-inch astrograph at the Lick Observatory was designed primarily for this purpose. Yale and Columbia Observatories are establishing an observatory in Argentina with a 20-inch astrograph to extend this work into the southern hemisphere. A programme with similar aims originates in Pulkovo Observatory. This relies chiefly on photographs with standard astrographic instruments established for the Carte du Ciel programme for connecting the positions of the stars and galaxies. It will take some time before these programmes give definitive results, but it must be expected that they will yield satisfactory standards of non-rotation. If they do not, the result will be startling and well worth the resources expended on the work.

Analysis of Observations

Positional astronomy is a field in which even the best accuracy that can be achieved is not as good as we would wish to have. Geodesy and celestial mechanics require an accuracy of $0''\cdot1$, and this is scarcely obtainable at present. For the determination of proper motions even higher accuracy is desirable. The motions are found by comparing the positions of the stars at two epochs as widely separated as possible and dividing the displacement in the interval by the time that has elapsed. The movements are very small. It was obvious that the Copernican system implied that the revolution of the Earth would yield parallaxes for the stars, that the stars were similar in character to the Sun, and that they must be in motion relative to one another and to any framework of observation that might be established. These facts were appreciated for example by Galileo, but the motions are so small that it was not until

1918, almost 200 years after Copernicus, that Halley first announced the proper motions for the bright stars Arcturus and Sirius. The motions of these stars would be quickly obvious now, but Halley used positions found at times 1,800 years apart. Out of the first 1,000 stars of one of the great Yale Catalogues (Yale Transactions, Vol. 20) of star positions in a well observed part of the sky 151 have motions in both coordinates less than twice their probable errors and only 75 have an annual motion in either coordinate exceeding $0''\cdot 1$.

Such a need for accuracy calls for instruments of great precision and stability. Suppose that the pivots of a transit instrument are 120 centimetres apart, then an error of $0''\cdot 1$ in the direction of the line of sight of the instrument corresponds to $0\cdot 6\mu$ error in either of the pivots. In general, both for fundamental instruments, and for photographic ones measuring relative positions, the stability and the accuracy of measurement sought is of the order of one micron or better. Although the transit instrument was set up to have more stability than its predecessors, it is obviously liable to distortion by the effects of changes in temperature of the surrounding atmosphere and elastic deformation which must occur under its own weight as it is moved into different positions.

The compilation of star positions requires the study of the individual catalogues from which the positions are drawn. Observations in any field in which refinement is sought are always subject to error with some of the results lying above the mean and some below. This is so with the position measures compiled at a particular observatory during any period. Although observations of the accuracy required for the determination of proper motions are often taken to begin with those of Bradley in the 1750's, it is clear that the trend towards increasing accuracy is gradually shortening the period over which it is profitable to gather observations. To show this, Table I (see Wood, 1960) gives the probable error of positions based on five observations as estimated in various periods during the past 100 years from the tables published in the General Catalogue. The value given represents the mean for the two coordinates, right ascension and declination.

If the individual measures of position at a single observatory are compared for a particular star, it will generally be found that the results are scattered about a mean value in roughly the fashion one would expect for errors arising in an accidental way because the work is being done at the limit of the available accuracy; but, when results from different sources are compared, it is usual to find that those from one catalogue consistently differ from those of another. The systematic differences in the star places remain fairly constant in one part of the sky but vary for different areas and even for stars of different brightness unless special precautions are taken to avoid what is known as magnitude equation. The source of these systematic errors must in part derive from insufficiently well determined instrumental errors or incorrect allowances for refraction but are in part obscure arising in differences of procedures at different places. A star always crosses the meridian of a given observatory at the same altitude, and any systematic error which depends on this will repeat indefinitely but may well be of a different magnitude at another observatory. The circle reading for a fixed direction in space varies from day to day or even in shorter periods, and this gives rise to errors which may be a function of the position of the star.

Table I

Equinox of Catalogues	Average Probable Error in One Coordinate
	$''$
1850	0·42
1875	0·32
1900	0·24
1925	0·18
1950	0·11

Having selected a set of catalogues, chosen because they have been observed in a fundamental manner and with the best accuracy, the compiler of a catalogue examines them for systematic differences and allots them importance in accordance with his estimation. He then establishes the mean places for as many stars as he can and finds systematic differences from the mean system for each catalogue. After the positions in the catalogues have been corrected for the systematic differences the positions should follow the law of chance errors and the positions should form a harmonious system which is regarded as fundamental. When this has been compiled, more catalogues can be brought to comparison with it to find what systematic corrections they need to bring their positions to the same basis as the fundamental catalogue. Then the systematic corrections may be applied to the positions of a star gathered from different catalogues corres-

ponding to different epochs of observation and its motion determined. The systematic differences between two catalogues as well as being functions of magnitude are generally taken, not necessarily with complete justifiability, to be in each coordinate of the form of the sum of two terms separately functions of the right ascension and declination. The systematic differences are not completely stable. The differences between Sydney " Catalogue of 1068 Stars " observed as a foundation for the system of our Astrographic Catalogue and the La Plata catalogues have been inferred from those of each as compared with the Albany General Catalogue ; but there are more stars common to the two catalogues than with the G.C., and the use of these gives appreciable differences in some parts of the sky. Systematic differences commonly have amplitude running to several tenths of a second of arc.

Many catalogues from individual observatories have been published in recent years. Of the compilations aimed at representing a fundamental system one that retains importance is the General Catalogue of 33342 stars for the Epoch 1950 (GC). This was compiled as a result of work over three decades of Lewis Boss and Benjamin Boss. It includes all stars to 7th magnitude and many fainter ones whose positions and motions were derived from many catalogues. One of the necessary activities during its compilation was an expedition to San Luis in Argentina, where many observations were made to strengthen the positions of Southern stars. Despite its admitted imperfections, the GC remains of great value because of the number of stars it contains providing among other things an intermediary between systems of catalogues which may contain few stars in common.

The most recent fundamental catalogue is the Fourth Fundamental Catalogue (FK4), which contains the positions and proper motions of more than 1,500 stars with best fundamental observations over the whole sky from material in more than 80 catalogues. This has been a large undertaking, and star places should be referred to this system for several decades. This had in fact already begun before the catalogue was published. The systematic differences from the FK3, the previous best fundamental catalogue published in 1939, are in several areas more than a tenth of a second of arc, and the epoch of the places is mostly before 1920 so that the errors in proper motions must make the ephemeris places even for years in the immediate future subject to some remaining uncertainty. The improvement of the Fundamental Catalogue presents a continuing problem to meridian astronomers.

Photographic Astrometry

In recent decades the great capacity of photography for obtaining relative positions has been exploited. Photographs of the same region at widely separate epochs enable relative motions of the stars to be obtained more accurately than in any other way. The same technique is used for finding the parallactic displacement of nearby stars relative to more distant ones, and the positions of members of the solar system are commonly found by photographing them against a background of stars whose positions are catalogued. The cataloguing of stars by this means began with the undertaking of the Astrographic Catalogue about 70 years ago, and the extension of star positions to include fainter magnitudes and greater numbers is now almost universally done by photography rather than by differential measurements with the transit instrument. Many programmes apart from the Astrographic Catalogue have been undertaken in this direction, most notably by Yale University Observatory, Hamburg Observatory and the Cape Observatory. The aim is to find the positions of the stars and to determine their proper motions by comparison with positions found at previous epochs. The positions obtained are of permanent value because they provide data for later determination of proper motions.

In principle, the processes of photographic work for the determination of star places are not complicated. The photograph from a theoretically perfect lens is a central projection of a portion of the sky on the photographic plate. If rectangular coordinates of stars on the plate are measured, the formulae of this projection can transform them to differences in right ascension and declination from the centre of the plate, provided that the centre of the plate is known and its orientation in the sky has been accurately determined from the stars of known position on the plate. The photographic observer needs a sufficient number of reference stars on the plate, not only to attach it to the sky in this way, but to determine, possibly by combining the results from many plates, the errors in the lens and in its adjustment as well as other effects which cause the images of the stars on the plate to depart from the position given by a true gnomonic projection. His aim must be to reproduce the system of the reference stars although, if his work is done

properly, there is a good chance that he will reduce the errors of the individual star places which are supplied to him by the meridian observer.

There are many errors affecting the positions of the star images on the photographic plate. These must either be eliminated by methods of observation, or by adoption of computational techniques in the comparison of the computed positions of reference stars with those that are accurately measured on the plate. E. H. Linfoot of Cambridge once remarked to me that if it was theoretically possible for an error to be present in a lens it would be certain to be there in some degree. In this kind of work every error that can be imagined must be guarded against. The errors depend on the magnitudes and colours of the stars as well as their positions on the plate. Description of methods of dealing with these is made unnecessary by the excellent and accessible account by Dieckvoss (1962).

At the present time an extensive plan for producing a catalogue of stars for the northern hemisphere is being carried on at Hamburg Observatory and plans have been formulated for similar work in the south.

Sydney Observatory

The work of Sydney Observatory in positional astronomy has for many years been associated with the production of a southern zone of the Astrographic Catalogue. The observatories of the southern hemisphere, being few in number were, by comparison with their resources, allotted large portions of the task and Sydney Observatory undertook the section with plates centred from $-52°$ to $-64°$. This lies along a rich section of the Milky Way for about eight hours of right ascension. It was planned to publish the work in 52 volumes and work has now so far progressed that the last volume of coordinates is in the hands of the printer, and only the introductory volume describing the work and providing facilities to enable it to be conveniently used is in preparation. The Catalogue lists the rectangular coordinates of the stars on the plates and aims to be complete to the 11th magnitude. The whole of the Sydney work contains the coordinates of over 740,000 star images.

Melbourne Observatory was also allotted a large zone covering all of the sky south of Sydney zone. Melbourne Observatory was closed in 1944 with only three volumes of a planned eight of the catalogue published. As a result of requests from the International Astronomical Union the records were transferred to Sydney Observatory and the remaining work undertaken here. The Union allotted funds for the publication. The manuscript of Volumes 4, 5, 6 and 7 was prepared and sent to Paris, where they were published, under the direction of Dr. J. Baillaud. Following his death it was decided to print the remaining volume in Sydney, and this year this volume also has been published and will soon be distributed.

The probable error of a single catalogue place in either the Melbourne or Sydney Catalogue is about $\pm 0''\cdot 36$ and at least two places are available for each star.

This work completed, Sydney is looking forward to using the old plate material for proper motion work, and this includes observation of a list of variable stars compiled by Plaut after the Groningen Conference on Galactic Research as well as the proper motions in some interesting areas such as star clusters.

Sydney Observatory has a programme for the observation of minor planets which culminate south of the equator. The minor planets which have been selected for purposes of fundamental astronomy mentioned earlier receive special attention. Each year several of these which are south of the equator receive a series of observations. In this case four exposures are made on each plate and the reductions carried out with more reference stars than are used for ordinary minor planets. From one plate the probable errors are $\pm 0''\cdot 010 \sec \delta$ in right ascension and $\pm 0''\cdot 14$ in declination largely owing to errors in the reference star places including the proper motions used to bring the positions of the stars to the epoch of observation and to emulsion shifts which must be different in different parts of the plate. Astronomical workers rightly point to parallax measurement as a difficult branch of observation, but in comparing positions of a minor planet obtained from separate exposures on one plate the parallax of the minor planet on account of the geocentric motion of the observer has to be taken into account. If it is not done, the right ascension from the later observation is almost invariably less than would be expected from the first observation, and this is after an interval which is usually only about 10 or 12 minutes.

Sydney Observatory has begun plans for new catalogue work. In our astrographic zone the old epoch positions will be obtained by re-measuring, with a long screw Hilger measuring machine, old astrographic plates which will be reduced with stars taken from the Cape Catalogues. The plates for the new epoch

positions will be taken using a Taylor, Taylor and Hobson lens which has been acquired in recent years. This gives excellent star images over a field 6° square and the average discordance between two measures on a star image with the Hilger measuring machine is 1·3 microns. Diffraction gratings will be used to deal with magnitude equation. The taking of the plates for this programme has been delayed for some months while awaiting the arrival of a new measuring machine, for it will be easy to keep the photography ahead of the measurement. The new measuring machine is being obtained from Grubb Parsons. The measuring agent in each coordinate is a moiré scale, the movement of which is controlled by optically worked slides at right angles. The machine will measure a plate 20 centimetres square. All the mechanical and optical parts and the plate will be in an enclosed thermostatically controlled space. The pointing is to be indicated electronically by patterns on two oscilloscopes, and it is claimed that setting will be possible to better than half a micron. The coordinates will be indicated by counters to show a digitized reading. Much of the computing work for the first part of this programme has already been done by the Utecom department of the University of N.S.W.

The Future of Positional Astronomy

Efforts must be continued to improve the fundamental system, not only to make it consistent over the whole sky but also to establish a more perfect standard of rest and to extend the number of accurate positions to include enough stars over the whole sky to serve as reference points for all purposes and to provide proper motions to fairly faint magnitudes for studies in kinematics of the Galaxy. The complete programme may be considered at three observational levels. First the fundamental observations, second the extension in number of the stars referred to the fundamental system to a number adequate for reduction of photographs in the third stage which consists in the determination of positions of the stars on the full programme.

The fundamental observer's future is related to the choice of instruments with which he must work and to their geographic distribution. There is need for development of new instruments in this field. Although at first sight the classical transit circle looks a stable instrument it is really very vulnerable considering that its work requires stability of better than a micron. By its nature it cannot be protected from variations of temperature and, as it must point in a great variety of directions, the flexures are not easy to determine and not necessarily in the meridian. The somewhat complex micrometer, too, is required to be stable in all positions of the instrument. The list of possible weaknesses could be carried further. Considerations of this kind, as well as the existence of systematic differences between the results from different places which occur despite the vigilance that is known to be necessary in this work, show that improvement is worth seeking.

The impersonal astrolabe of Danjon does not appear to be a complete answer to the problem. The great circle traced by the transit circle is a more advantageous shape for scanning the sky as the Earth rotates than the small circle around the zenith provided by the astrolabe. It has in principle no places where the observation of either right ascension or declination falls off markedly in accuracy. There should be something to be learnt from the remarkable freedom of the astrolabe from systematic error depending as it does on a sound kinematic basis and on the stability of just one component, the angle of the prism, which defines its degree of freedom in positive relation to one of the identifiable points of the celestial sphere, the zenith. The design itself of the future instrument must remove from the instrument the errors that have had to be so carefully investigated in the past. Danjon (1960) himself has made suggestions for the construction of a transit instrument which by a geometrical device may overcome some of the disadvantages of the transitional transit circle. In four northern observatories mirror transits have been constructed and it is obvious that they deal with some of the objections, notably with flexure. They are however in initial stages of their use and may prove to have new disabilities. Do they for example introduce new difficulties with refraction ?

The question is of such importance that the problem is well worth an elaborate design study such as is undertaken preliminary to the construction of a great reflector. There are many suggestions, some of which have been under study, which could be taken into account.

1. Circle readings should be digitized to the full accuracy of readout rather than photographed in a form suitable for automatic measurement.

2. It may well be possible to design an instrument without the usual micrometer. The photographic and photoelectric devices that have been tried might well give assistance here.

If necessary a return to the old situation in which right ascensions and declinations are measured by different instruments should not necessarily be avoided. This is not a radical suggestion for observers in recent years have often engaged in programmes for measurement of only one coordinate.

3. Digital readings could lead to automatic operation of the instrument. This is not meant merely to save the observer labour but to remove him from the vicinity of the instrument where, it has been proved, his body temperature can give rise to trouble.

4. If the instrument depends on a geometric principle as the prismatic astrolabe does, it might be worthwhile to set it high above the ground where it is now claimed better seeing can be expected. Danjon says that on good nights the astrolabe results are appreciably better than on poor ones. In any case the experience of atmospheric seeing during the search for better observing conditions during both day and night might make a contribution to the design of more stable and more easily observed azimuth marks.

5. A reading of the description of the transit circle reveals that from the thermal point of view the materials of which it is usually made are far from being the most suitable. If they are structurally so desirable, it should be possible to add auxiliary stabilizing components. Such a plan has worked in Schmidt systems which are sensitive to failure of adjustment. As an example it may be possible to arrange an optical system including a mercury bath to ensure that the axis of the instrument is held horizontal by a servomechanism.

Extension of the Fundamental System

It is necessary to provide enough reference star positions for the photographic programme. This might be done by extending the fundamental programme to include enough stars, but more usually some of the work is transferred to programmes of transit work done differentially to extend the observations to a satisfactory number of stars. This is easier to do in the northern hemisphere where the number of transit circles is more adequate than in the south.

The burden may be largely lifted from the transit observer by the use of a very wide-angle camera for catalogue work as has been suggested by Brouwer (1960). If the transit observer had fewer stars to observe, he could concentrate more attention on his fundamental system. Brouwer suggested that a field 20° square might be photographed with a lens rather shorter in focal length than is usual for positional work. Naturally the accuracy of individual position measurements would be less. Deviation from flatness of the glass would be more senious but it might be possible to measure the deviation at the positions of the programme stars on the plate. Repetition of the measures and much overlapping of the areas photographed should reduce these errors. With such wide angle it may well be necessary to do all the computation in the form of apparent places, including the effects of refraction. The number of stars measured need not be large by the standard normally accepted by the photographic observer since the aim would be only to provide enough reference stars for reduction of instruments of longer focal length. The important aim would be to avoid introduction of any systematic error for the long focus observations would reduce the accidental errors. I do not know whether any progress has been made towards such a project. On the other hand, Eichhorn (1960) has shown that by arranging the photographic programme with suitable overlaps fewer reference stars are needed.

Another project suggested by Brouwer is the establishment of a revised General Catalogue. The epoch of the General Catalogue is now so far in the past as to make serious the effect of errors, systematic and accidental, of reduction to the present epoch. The undoubted usefulness of the old GC make inevitable a similar compilation. The idea is further developed by Fricke (1962), who proposes that it can be based on the FK4.

Zone Observations by Photography

The photographic zone observations, by which the great mass of the fainter stars are catalogued, may be improved in accuracy by using longer focal lengths and, with Eichhorn's suggestion in mind, there is a tendency to suggest the use of smaller fields than have been customary for some years now. There must still be a compromise here for, if much reliance is placed on the computational process and the field made small, some flexibility is lost. For the zone work a field 4° square might be a suitable compromise. The 17-inch square plates of which we in Sydney took a number in 1955 and 1956 for a programme of Yale University Observatory, are not far from the largest practical size. Brouwer and Vasilevskis agree with this. This size and field combine to give a focal length about 220 inches. For catalogue purposes good images are a requirement but a large aperture is not

needed. An aperture of 8 inches, or even 6 inches would be ample to ensure reaching the desired magnitudes with reasonable exposures and experience with the astrometric lens at Sydney seems to show that a designer permitted to reduce the aperture ratio to 1 : 30 would have no difficulty in supplying very good star images over the whole of the suggested field. Such a programme might reduce the probable error for a catalogue place depending on results from several plates to $\pm 0''\cdot 05$.

This instrument would require a companion measuring machine. Electronic bisection offers enough superiority in accuracy and in freedom from personality to make it imperative. Our experience here is definitely in support of the view of experts in metrology, and of at least some astronomers, that the long screw should be replaced as a measuring agent. We acquired such a machine of excellent quality in 1951, since when it has been in use for about ten hours per week. It now shows very obviously the effect of wear although it has been lubricated regularly in accordance with the best recommendations we were able to obtain. A machine for extensive catalogue work must withstand a great deal of use, and it must be better to rely on a scale of some kind which would not suffer from the effects of mechanical wear.

The Southern Hemisphere

An astronomer of the southern hemisphere must refer particularly to the weakness of the positional astronomy in the Southern Sky. Constantly we see references to projects in the north which are not practical in the south. One example of this is in the revision with encouraging results of the plate constants of the astrographic catalogue for some zones. This would not be satisfactory in the south. F. P. Scott (1962), in a statement on the preparation of the FK4 in the Report of Commission 8 of the International Astronomical Union, says that the work " clearly indicates the necessity for more series of absolute observations in the southern hemisphere ". W. Gliese (1962) in the discussion pointed out that the errors increase south of $-25°$ and beyond $-70°$ they become considerable. An examination of the GC (Irwin, 1960) shows that the probable errors of positions and proper motions south of $-30°$, about the limit that can be reached by a northern observatory, are seriously higher than those in the north. This is despite the valuable expedition to Argentina by the Dudley Observatory in 1909.

The reason for this situation is painfully obvious. In the same Commission 8 report 29 instruments which are engaged in meridian astronomy in the northern hemisphere are mentioned and only six in the south. The disparity in resources is a good deal greater than this indicates because several of the northern observatories have resources for this work greater than the southern observatories, and some of the northern instruments are of more recent construction or much modernized. The situation will only be partly improved by the expedition by Pulkovo Observatory to Chile and the projected expedition by Hamburg Observatory to Perth. The true solution is for additional instruments to be permanently established by southern countries. If the encouraging amount of experiment on instruments in this field should lead to clear improvement in the near future, it will be more important to place the improved instrument in the southern hemisphere than to yield to the temptation to modernize one of the instruments which have been set aside by northern observatories who, following the fashions of the time, have turned from positional work.

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Our Permian Heritage in Central Eastern New South Wales*

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Mr. President, Mrs. Clarke, Ladies and Gentlemen—

It is indeed very gratifying to have the opportunity of adding a little to all that which has been done by previous Clarke Memorial Lectures in perpetuating the memory of the Reverend W. B. Clarke and his part in the geological pioneering of Australia.

The subject of this lecture was chosen with a view to its being of general geological interest. It is concerned largely with the geomorphology of the Central Eastern Highlands between Lithgow, Mudgee, Wellington, Orange and Bathurst. The lecture makes no significant inroads in new knowledge into previously established Tertiary and Pleistocene physiography. Rather it presents, in a popular way, some new ideas provoked by results of recent research into the palaeogeography of the region from Mid-Permian through Mesozoic to early Tertiary time. It depends on distribution, nature and mode of occurrence of Permian sediments outcropping along margins of the Sydney and Oxley Basins, and forming outliers scattered across wide areas of older Palaeozoic basement rocks.

From the study of field evidence, many of the broad topographical features in Central Eastern New South Wales appear as a Permian heritage, passed down from an ancient drainage system of far greater antiquity than the Tertiary elevation of the present Eastern Highlands.

The Stripped Unconformity and the Miocene Surface

Marginal Permian sediments are well known along the western side of the Sydney Basin from Burragorang to Lithgow and Rylstone (Fig. 1). They outcrop from beneath Triassic sandstones, rise west towards the Main Divide, and disappear where they have been stripped by erosion from the unconformable surface on the metamorphic basement. The old stripped surface continues to rise to the west until, at places such as Hampton and Yetholme, it is higher than Permian and Mesozoic rocks from beneath which it emerged away to the east (Fig. 2). At this level, rising above 4,000 feet in some places, the stripped unconformity becomes the general plateau surface partly dissected by headwaters of both eastern and western rivers in the vicinity of the Main Divide. Outliers of Permian, standing as high erosional residuals, bear evidence of the fact that the plateau surface is the stripped unconformity.

From vantage points such as Hassan's Walls, it can be seen that the Miocene peneplain, developed in Triassic rocks on the Blue Mountains, passes west and merges with the stripped unconformity, cut in basement rocks, on the Main Divide. From other vantage points such as Cherry Tree Hill and Blackman's Crown, it can be seen that these two surfaces, on passing west of the Main Divide, again assume their separate identities (Fig. 3). The Miocene surface falls to the west and becomes the general upper level of country into which headwaters of the Macquarie and Turon Rivers have been deeply entrenched. The stripped unconformity continues to rise to the west, as seen in far-flung Permian remnants such as Mt. Bocoble and Mt. Carcalgong. These stand high to the west of the Main Divide above the general Miocene level. They are capped with basalt flows which preserved them from erosion during Miocene peneplanation.

Remote Permian Outliers and Valley Deposits

North of Rylstone, Permian and Triassic sediments pass from the Sydney Basin to the Oxley Basin, and assume a north-easterly dip. Marginal outcrops of Permian extend north-west from Rylstone to Cooyal and Ulan, then west over the Main Divide, to the Gulgong-Dunedoo region (Fig. 1).

South and south-west of the marginal Permian outcrops between Rylstone and Dunedoo, the country is generally occupied by older Palaeozoic

* Clarke Memorial Lecture delivered in Science House, Sydney, on 29th June, 1961.

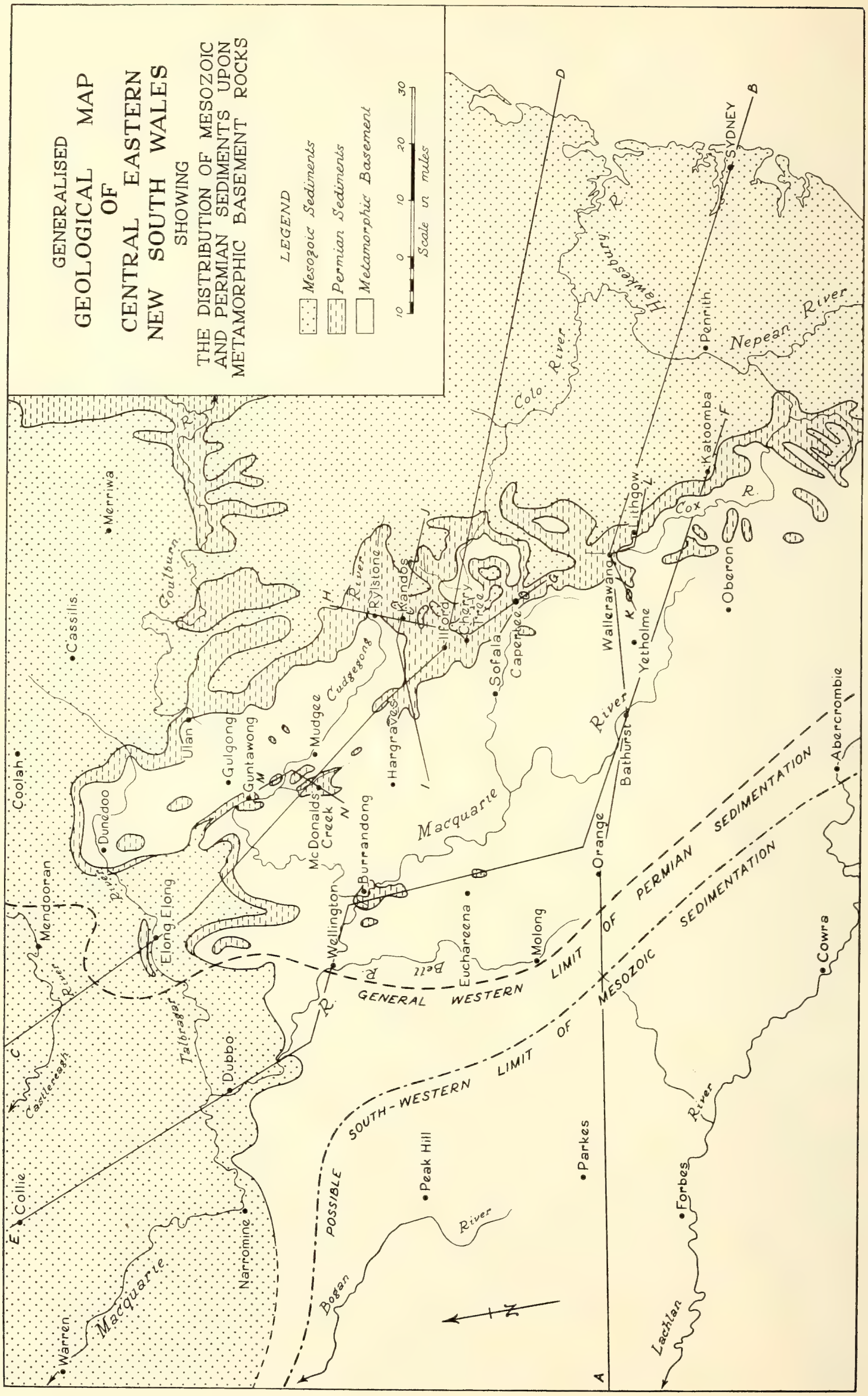
GENERALISED
GEOLOGICAL MAP
OF
CENTRAL EASTERN
NEW SOUTH WALES
SHOWING
THE DISTRIBUTION OF MESOZOIC
AND PERMIAN SEDIMENTS UPON
METAMORPHIC BASEMENT ROCKS
LEGEND
Mesozoic Sediments
Permian Sediments
Metamorphic Basement
10 0 10 20 30
Scale in miles
GENERAL WESTERN LIMIT OF PERMIAN SEDIMENTATION
POSSIBLE SOUTH-WESTERN LIMIT OF MESOZOIC SEDIMENTATION
Warren
Collie
Coolah
Cassilis
Merriwa
Mendooran
Dunedoo
Gulgong
Ulan
Guntawong
Mudgee
Rylstone
Kandos
Ilford
Cherry Tree
Sofala
Capertee
Wallerawang
Lithgow
Katoomba
Penrith
SYDNEY
Oberon
Yetholme
Bathurst
Abercrombie
Orange
Molong
Euchareena
Burrandong
McDonalds Creek
Hargraves
Wellington
Elong Elong
Dubbo
Narromine
Peak Hill
Parkes
Forbes
Cowra
Macquarie
Castlereagh River
Talbragar
Goulburn R.
Cudgegong River
Bell R.
Colo River
Hawkesbury R.
Nepean River
Cox R.
Bogan River
Lachlan River
A
B
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FIG. 1

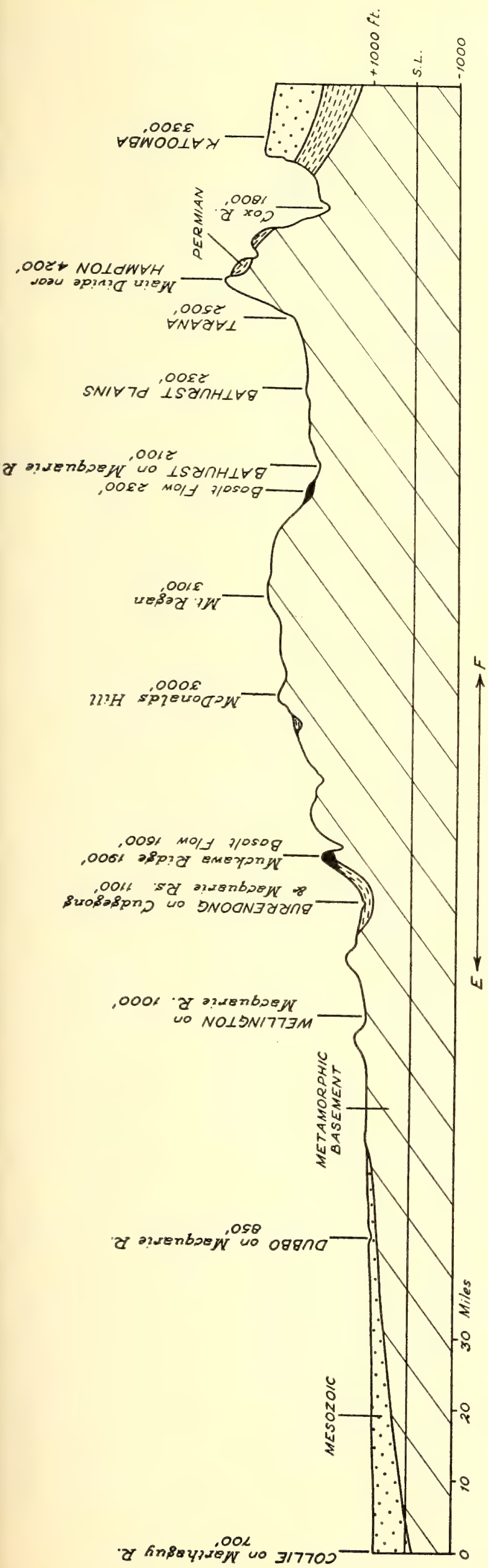


FIG. 2.—Section along E–F in Fig. 1, showing Relations between Topography and the Stripped unconformity

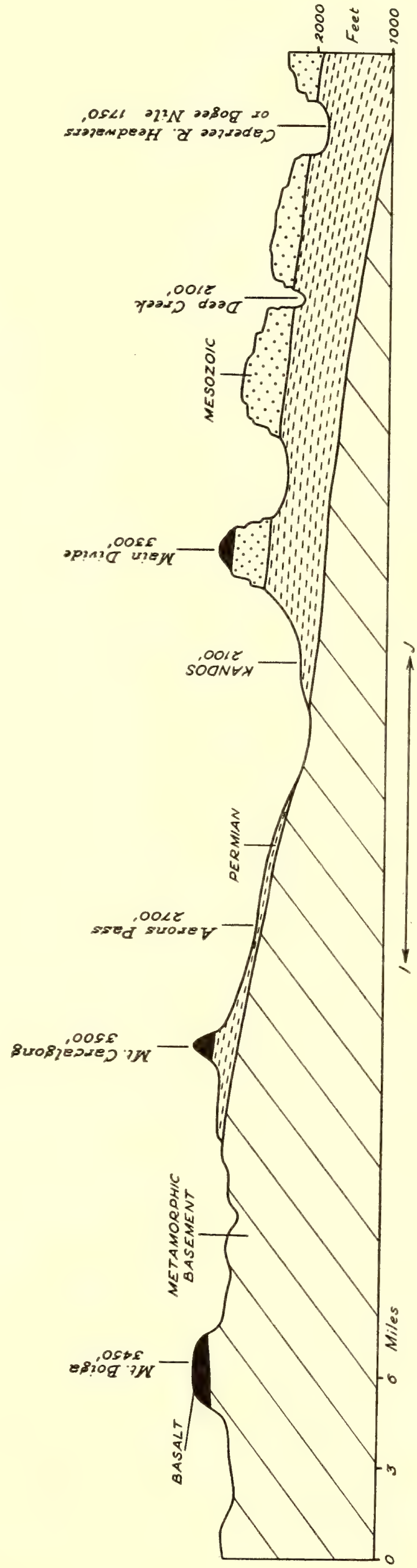


FIG. 3.—Section along I–J in Fig. 1, showing Relations between Topography and the Stripped Unconformity

basement rocks. However, in this wide area of older rocks, between Bathurst, Mudgee, Wellington and Orange, several small secluded outliers of Permian sediments have been found. These remote occurrences have provided all important clues to Permian and Mesozoic history of much of Central Eastern New South Wales.

In valleys of the Cudgegong River and MacDonald's Creek, west and south-west of Mudgee, there occur outliers of Permian sediments in which *Gangamopteris*, *Vertabraria* and *Phyllotheca* have been found. They consist of fluo-glacial conglomerates with erratics and ice-scratched pebbles, sandstones, mudstones and well-developed varve shales (Dulhunty and Packham, 1961). A remarkable feature of these sediments is the fact that they lie on flat floors of steep-sided valleys eroded out of Silurian and Devonian basement rocks (Fig. 4). Today the valleys are occupied by the Cudgegong River and its tributary, Macdonald's Creek. The steep present-day valley sides of basement rock evidently represent steep sides of fiord-like estuaries in which sediments were deposited in Permian time. The present-day valleys must have been developed by re-excavation and removal of Permian sediments during the Tertiary and Pleistocene.

Somewhat similar beds occur on the valley floor at the junction of the Macquarie and Cudgegong Rivers, near Burrandong, a little east of Wellington. This deposit has been described in some detail by Burgess (1960). Here again it is evident that the present-day valley has been developed by removal of soft Permian sediments from an old Permian valley which became an estuary when drowned by the rising level of the Permian ocean (Fig. 2).

Still more remote from present-day areas of Permian rocks is another isolated occurrence of conglomerate and mudstone, near Euchareena, some twenty-five miles north-west of Orange (Fig. 2). These sediments, originally discovered by G. H. Packham, contain *Phyllotheca*, and Permian microspores have been recognized by R. Helby. They appear to represent estuarine deposits on an old valley floor situated at a level intermediate between the present-day valley of the Macquarie and the Miocene peneplain surface.

The Significance of Permian Valley Deposits

The Permian beds occurring on the floors of present-day valleys do not exceed 300 feet in thickness. The valleys, which are steep-sided, vary from 500 to 1,500 feet in depth. They must have been completely filled with Permian and younger sediments until late Tertiary or Pleistocene time, otherwise the upper portions of valley sides would have been exposed to erosion ever since Permian time and would have been eroded back a long way by now.

It would also seem as though Triassic and even Jurassic sediments must have overlain the Permian in the valleys. Some of the Permian valley deposits along the Cudgegong River are continuous with beds in the main Permian areas to the north, and others may be readily correlated with them. Valley deposits at Burrandong were almost certainly continuous with marginal Permian beds north of Wellington before being separated by erosion. Marginal beds bordering the main Permian areas to the north are near-shore deposits and relatively thin, varying from about 200 to 400 feet in thickness. Estuarine deposits along the actual shoreline, now occurring as valley deposits, could not have been thicker than the near-shore deposits with which they are continuous. However, valleys containing estuarine sediments are between 500 and 1,500 feet deep and must have been completely filled (Fig. 5). Therefore, the Permian deposits, which were less than 400 feet thick, must have been covered by Triassic sediments. Furthermore, Triassic beds overlying Permian in marginal areas are also very thin and frequently overlapped by thick Jurassic beds on to the basement. Thus it is possible that Triassic and even Jurassic sediments were deposited in the valleys above Permian beds before late Permian topography was completely drowned, and widespread deposition of Jurassic sands covered the whole area. This is known to have happened between Gulgong, Elong and Dunedoo, where Permian, Triassic and Jurassic sediments all occur in conformable sequence in one valley of basement topography (Dulhunty, 1939).

Where late Permian, Triassic and early Jurassic sediments occur in one and the same basement valley, it is difficult to escape the conclusion that tops of valley sides must have been exposed to erosion throughout the whole of the Triassic, and so reduced by erosion to mere shadows of their original height. This must surely mean that lofty mountain ranges towered perhaps 20,000 feet above valley floors in late Permian time, and that they were reduced to ridges less than 1,500 feet high before being covered by Jurassic sands and protected from further erosion.

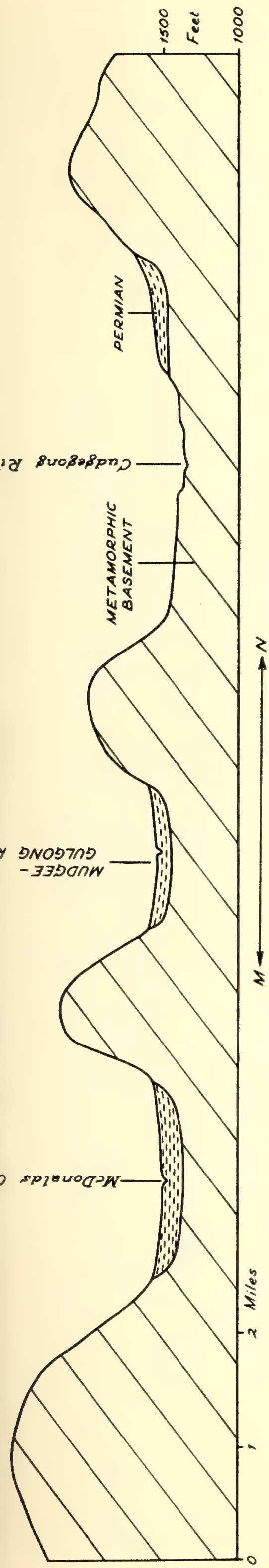


FIG. 4.—Section along M–N in Fig. 1, showing Permian Sediments in Basement Valleys

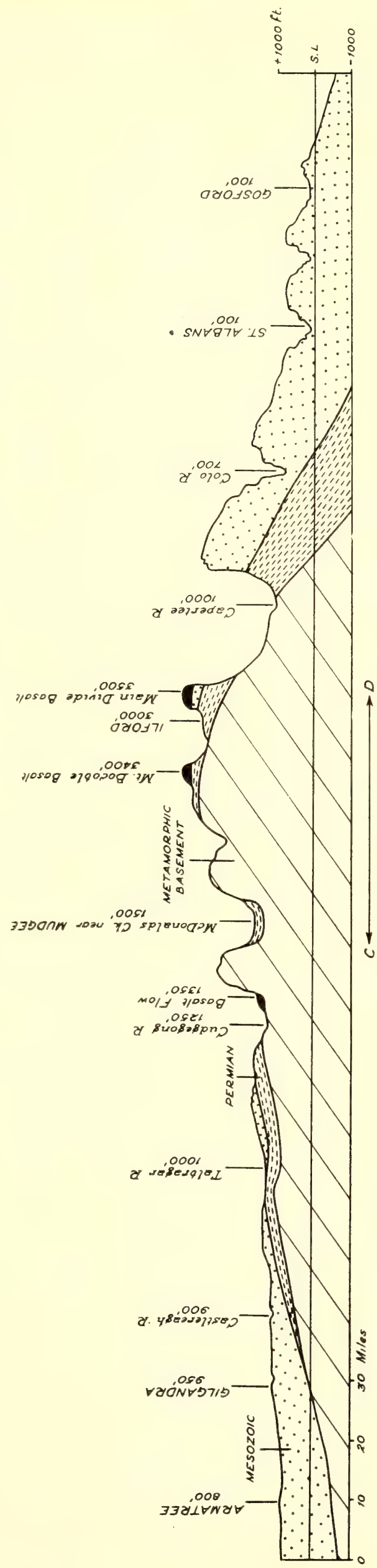


FIG. 5.—Section along C–D in Fig. 1, showing Relations between Permian Shoreline Sediments and Basement Relief

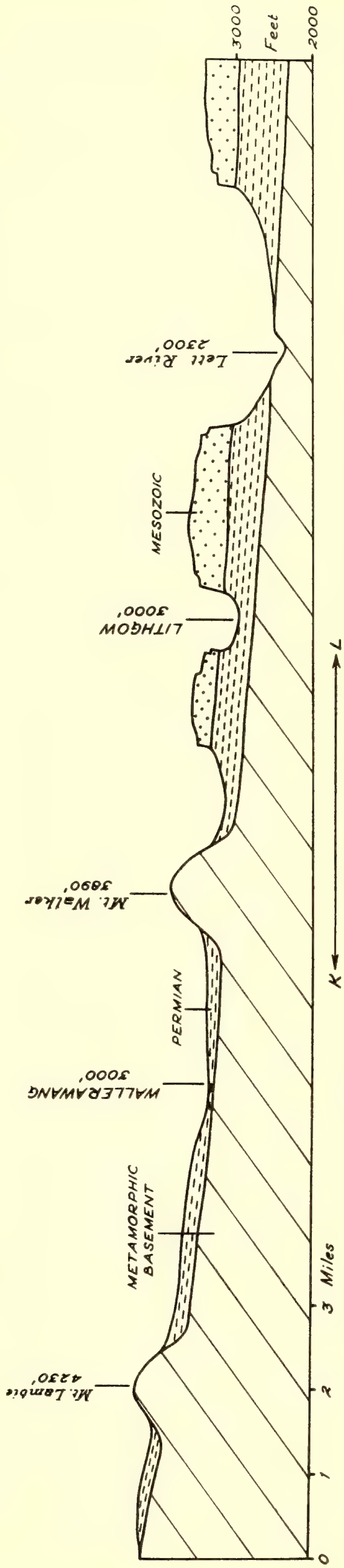


FIG. 6.—Section along K–L in Fig. 1, showing Basement Relief near Lithgow

Basement Relief and Permian Topography

The study of the unconformable surface between basement rocks and Permian sediments has revealed marked variation in basement relief from place to place. This is directly related to variation in topographical environment at the time of deposition of late Permian sediments. The different kinds of basement relief fall into three main groups. The first is a generally planar surface with very minor features and gently undulating topography. This type of surface is typical of the unconformity near Rylstone and Kandos, as illustrated in Fig. 3. It undoubtedly represents a senile or very mature land surface, or coastal plane, across which the shoreline advanced quickly as a result of a relatively small rise in sea level.

The second kind of basement relief is an undulating surface with isolated " basement highs " of the nature of small and rather steep-sided hills rising above the general level of surrounding basement. This kind of surface is well developed near Lithgow (Fig. 6), where Mt. Walker, Mt. Lambie and other hills of basement rock rise above the level of the surrounding unconformable surface still partly covered by Permian sediments. The isolated hills are erosional residuals of hard rock developed by differential erosion. They must have been islands in the Permian sea, before complete submergence and burial beneath sediments. Their relatively steep sides are probably due to shoreline erosion and wave action when they were islands.

At several places, overlapping occurs on the flanks of isolated hills of basement rock. Near Wallerawang, at the junction of the Bathurst and Mudgee roads, Permian marine beds are overlapped by coal measures which in turn are overlapped by Triassic sandstone. This represents a problem somewhat similar to the occurrence, already described, of Permian, Triassic and Jurassic sediments in one basement valley. It means that the upper surface of the basement high was exposed to erosion during the whole of the time in which coal measures were deposited, and its height must have been reduced very considerably before submergence beneath waters of the Triassic lakes.

The third kind of basement topography is that developed where estuarine deposits of Permian and Mesozoic sediments occur in valleys carved out of basement rock. It is typical where deposits of Permian occur along the Cudgegong valley and its tributaries west of Mudgee (Fig. 4), and in the Macquarie valley at Burrandong. The unconformable surface actually forms the valley floor, and then passes up steep valley sides and over wide low ridges. It is a composite type of basement relief, formed by changing conditions over long periods of time. In its early stages it represented youthful topography in a mountainous terrain where, in late Permian, glaciers extended down from great mountain heights into valleys which had been drowned by a rising sea level to form estuaries along a rugged coastline. Its later stages of development were set in a much more mature scene. After high snow-covered peaks and ridges had been eroded away, nothing but broad flat ridges separated the estuaries. These, by now, were little more than embayments almost filled with fresh water, along the shores of great Mesozoic lakes extending far beyond the northern horizon. Then, with further rise in base-level, lake waters crept over the sides of the estuaries. By mid-Jurassic time, water commenced to spread across low, flat intervening country, producing a vast senile swampy area where great snow-covered peaks and ridges had once towered above the coastline of a Permian ocean.

The Regional Permian Picture

The distribution of valley deposits and other Permian outliers, the extension of the stripped unconformity from the Sydney Basin west of the Main Divide, and the trend of overlapping of Permian by Mesozoic, strongly suggest a complicated Permian shoreline in late " Upper Marine" time, as illustrated in Fig. 7. In this palaeogeographical map, an attempt has been made to trace the actual shoreline, based on evidence already reviewed. The general trend of the coast was from south-east to north-west, through Lithgow, Mudgee and Dunedoo ; however, it was complicated by great embayments and large islands, in a general setting of snow-capped coastal mountains.

Granite areas of the present-day Bathurst Plains almost certainly provided low-lying country in late Permian time. Careful studies of relative levels of Peimian deposits on granite and adjoining metamorphic rocks, between Mt. Lambie and Hampton in the Lithgow district, leave little doubt that the Bathurst Plains formed a large bay in the late " Upper Marine " shoreline. It follows that late Permian sediments must have been deposited over low-lying granite country where the Bathurst Plains have since developed largely by removal of soft Permian sediments. An even larger embayment seems to have existed further north, where

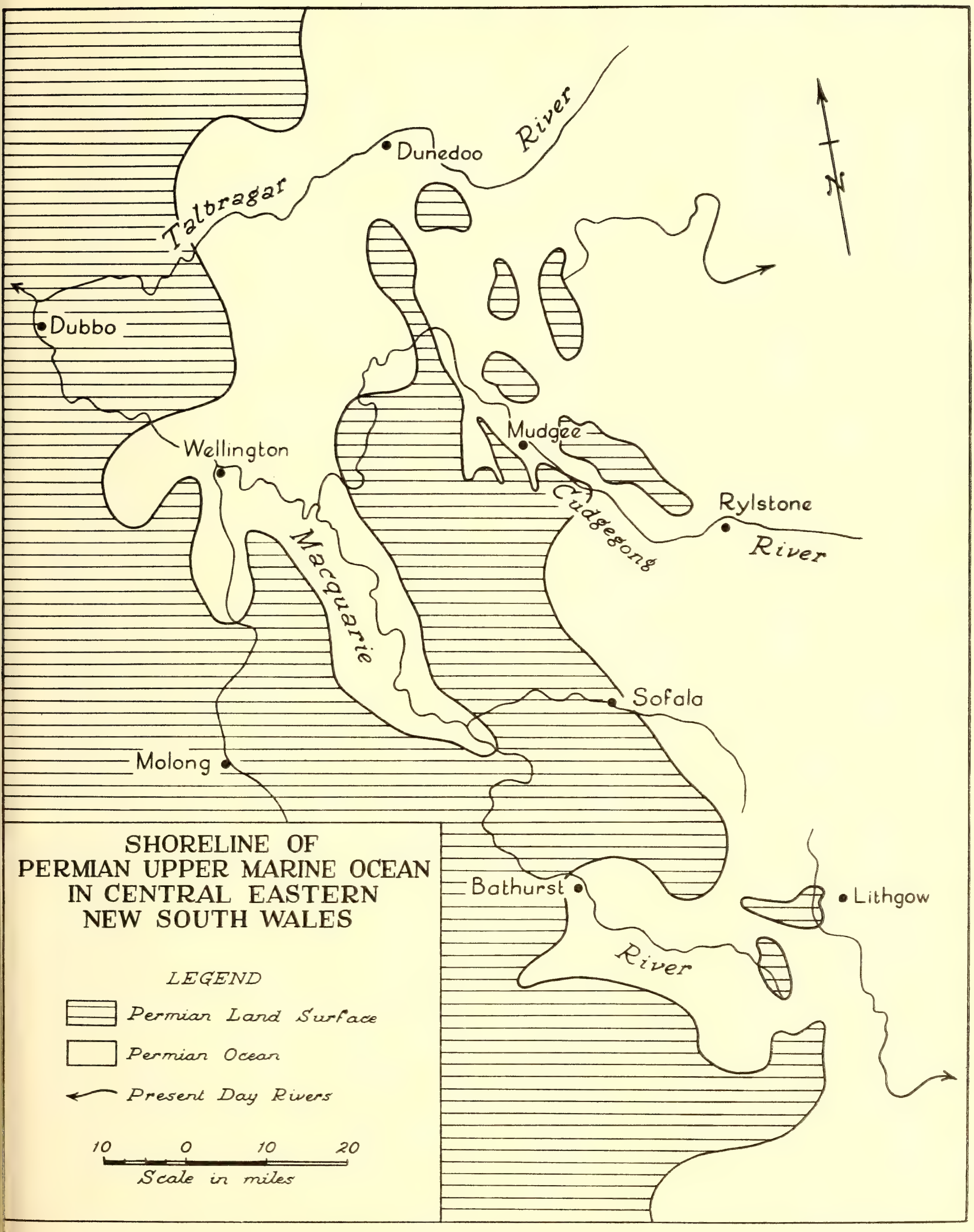
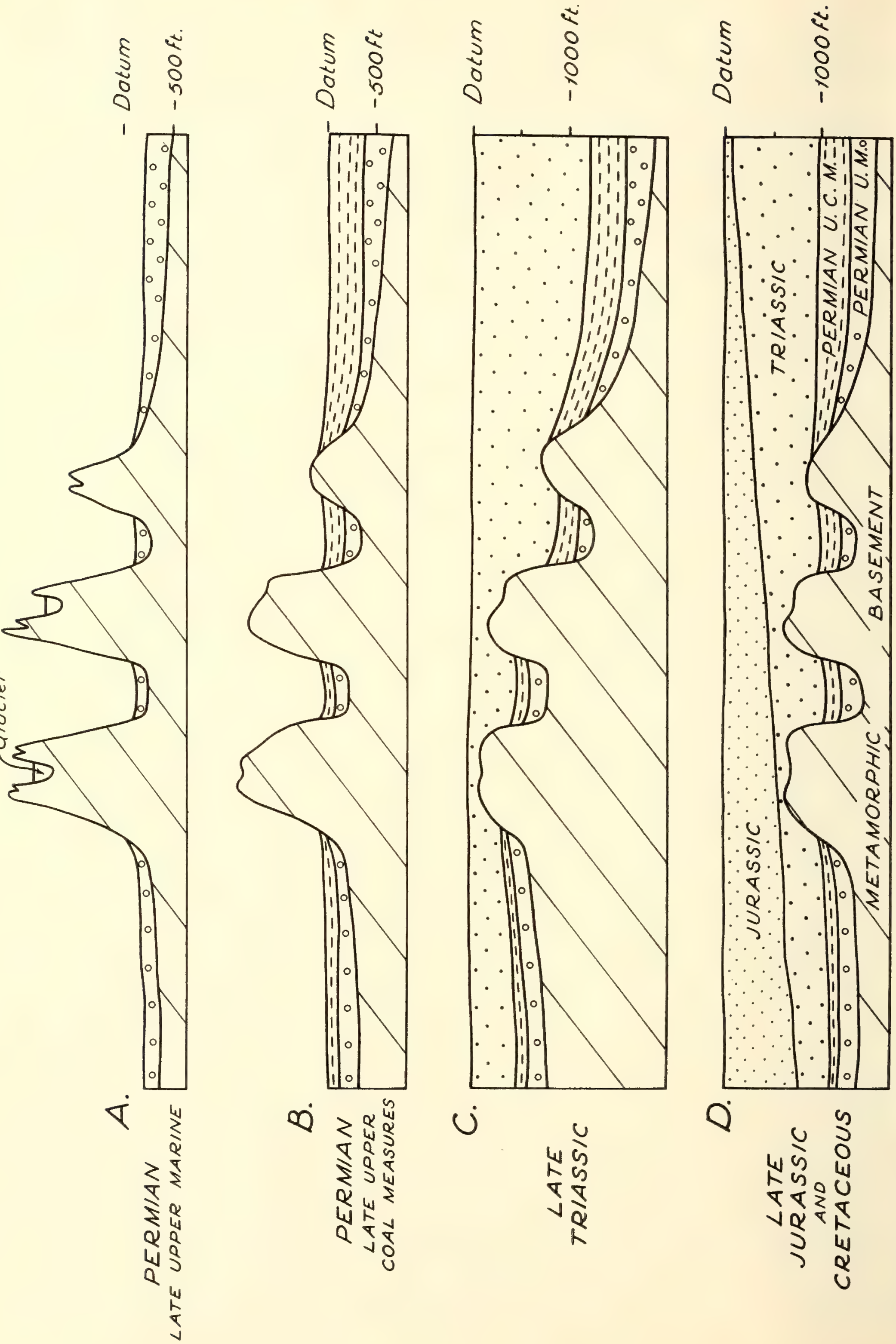

Dunedoo
River
Talbragar
N
Dubbo
Wellington
Mudgee
Rylstone
Cudgegong
River
Macquarie
Sofala
Molong
SHORELINE OF
PERMIAN UPPER MARINE OCEAN
IN CENTRAL EASTERN
NEW SOUTH WALES
Bathurst
Lithgow
River
LEGEND
Permian Land Surface
Permian Ocean
Present Day Rivers
10 0 10 20
Scale in miles

FIG. 7



A.
PERMIAN
LATE UPPER MARINE
Glacier
Datum
-500 ft.
B.
PERMIAN
LATE UPPER
COAL MEASURES
Datum
-500 ft
C.
LATE
TRIASSIC
Datum
-1000 ft.
D.
LATE
JURASSIC
AND
CRETACEOUS
Datum
-1000 ft.
JURASSIC
TRIASSIC
PERMIAN U.C.M.
PERMIAN U.M.
METAMORPHIC
BASEMENT

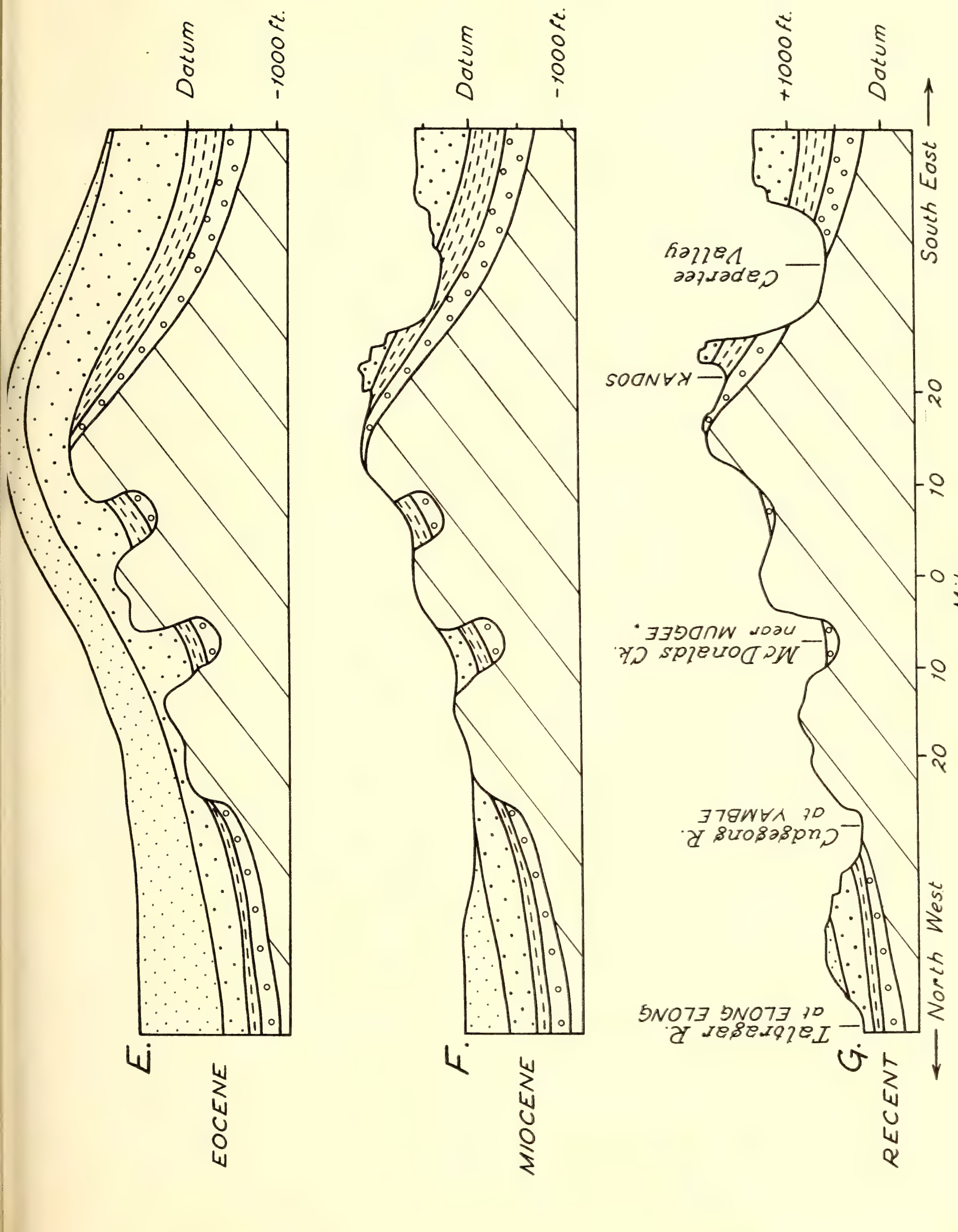


FIG. 8.—Sections illustrating the Development of Geology and Topography in the Eastern Highlands near Mudgee

ocean waters extended south-west from Dunedoo to Wellington, and then south-east in a long narrow arm, or drowned estuary, probably to the vicinity of the present-day junction of the Macquarie and Turon Rivers (Fig. 7). The Macquarie and Turon River valleys of today would seem to have been formed mainly by removal of Permian sediments from valleys originally excavated by a Permian river system and then drowned by the rising level of ocean waters in late Permian time.

The general south-east to north-west trend of Permian coastline through Lithgow, Mudgee and Dunedoo was determined by a similar trend in high mountain ranges. Actual positions of many of the old ranges can be seen today where Permian sediments are overlapped by Mesozoic beds along flanks of basement highs which represent eroded stumps of the original mountains.

The Changing Scene from Permian to Recent

If all the geological features so far discussed are fitted together like pieces of a jig-saw puzzle, there emerges a changing scene of events from about mid-Permian to Recent. The topographical, structural and stratigraphical consequences of major events in this history are illustrated in Fig. 8. The six sections, A to F, are intended to represent progressive stages in development of present topography and geology as seen in section G, across the Main Divide from Capertee Valley on the east to the Talbragar River, between Dubbo and Dunedoo, on the west. The datum horizon indicated on each section corresponds to present sea level, and changes in its relative position from one section to another are intended to indicate the extent of subsidence and uplift at different stages in the history of the area.

Section A

Commencing at about mid-Permian, it appears that high mountains, running generally from south-east to north-west, existed in the same general area as the present Eastern Highlands and Main Divide. They carried permanent snowfields, and glaciers moved down valleys into estuaries of the Permian Ocean lying to the north-east. It was a period of general subsidence and ocean waters gradually moved further up valleys and drowned foothills of mountains.

Section B

Towards the close of Permian time, the ocean was replaced by freshwater lakes and swamps, and mountains had been reduced in height and ruggedness. Freshwater sediments and peat beds were deposited upon the marine strata. Subsidence was more pronounced east of the mountains, where greater thicknesses of coal measure sediments were deposited in the Sydney Basin. Only thin and somewhat discontinuous beds of late Permian freshwater sediments were deposited north and west of the mountains.

Section C

General subsidence of the whole area continued throughout the Triassic. It continued to be more pronounced to the east. This resulted in deposition of large thicknesses of sediments in the Sydney Basin, and a general tilt of the old basement surface to the east. Erosion of mountains continued during the first half of the Triassic but later in the period, with continued subsidence, mountains which had now been eroded down to mature upland hills were eventually submerged beneath water and sediments of Triassic lakes.

Section D

On passing into Jurassic time, the main areas of subsidence moved from the Sydney Basin on the eastern side of the area to the Great Artesian Basin on the north-west. This resulted in levelling off of old basement surfaces which had been tilted to the east during the Triassic, and also deposition of appreciable thicknesses of Jurassic sediments to the north-west. The present-day thickening of Triassic sediments to the east and Jurassic sediments to the north-west is a consequence of shift in position of the main area of subsidence.

Section E

An uplift of perhaps 2,000 feet appears to have occurred in late Cretaceous or early Tertiary time. This marked the culmination of a long period of subsidence which had gone on almost continuously from early Permian to late Mesozoic.

The uplift produced a narrow range of elevated country trending north and south in a position close to that occupied previously by Permian mountains, and also that of the present Eastern Highlands produced subsequently in late Tertiary time during the Kosciusko epoch.

The early Tertiary range must have provided a " main divide " in central eastern New South Wales, with eastern- and western-flowing rivers similar to the present-day situation. Soft Mesozoic sediments were quickly removed from the elevated country by erosion during early Oligocene time.

Section F

Then followed a long period of peneplanation which produced a mature undulating surface, rising to perhaps 1,000 feet above sea level,by the time Miocene lateritization commenced.

The mature Miocene hills, still providing a " main divide " between eastern and western drainage, had been carved largely from basement rock. However, large patches of Mesozoic and Permian sediments remained inlaid in the Miocene surface where they filled old valleys, or one-time estuaries, of lakes and seas.

East and west of the early Tertiary hills the old Miocene surface extended in extreme senility across Mesozoic sediments which, as yet, had not been elevated at all.

Section G

During Pliocene time, uplifting of the Kosciusko Epoch commenced and eventually lifted the old Miocene surface by an additional 2,000 to 3,000 feet to an elevation of between 3,000 and 4,000 feet above sea level. During and following the Pliocene uplift, the old Miocene surface was further dissected by the entrenchment of old streams which originated as a consequence of the early Tertiary uplift—following then, as now, some general trends of an ancient drainage system which has become our Permian heritage.

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Geology and Sub-surface Waters of the Jurassic Walloon Coal Measures in the Eastern Portion of the Coonamble Basin, New South Wales

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Abstract—The Jurassic Walloon Coal Measures are represented in the eastern portion of the Coonamble Basin by the Purlawaugh and the Pilliga Beds. The Purlawaugh Beds are encountered beneath the Pilliga Beds only in topographic depressions in the surface of the Palaeozoic basement complex. West-north-west–trending basement ridges characterize the eastern portion of the Coonamble Basin. The Walloon Coal Measures decrease in thickness towards the west. Decrease in the thickness of the Pilliga Beds is also to the west, for the formation becomes more shaley in that direction. The main aquifers of the Walloon Coal Measures are within the Pilliga Beds. The thicknesses of the shales which separate the aquifers are variable. Figures for the total solids content of some of the bore water are given.

Introduction

The present paper deals with the Jurassic stratigraphy and hydrology of some 2,200 square miles in the eastern portion of the Coonamble Basin of New South Wales. The area under consideration is bounded to the west by a line joining Coonamble in the south and Walgett in the north, and it extends eastwards to the flanks of the Warrumbungle Mountains (Fig. 1).

Stratigraphy

In the eastern portion of the Coonamble Basin, the Jurassic System is represented by the Walloon Coal Measures, outcropping to the east of the area under consideration (Kenny, 1927, 1928; Hanlon, 1950; Mulholland, 1950; David, 1950). Jurassic sedimentation commenced in some areas with the deposition of the Purlawaugh Beds, and this Formation is overlain by the Pilliga Beds. The latter contain the main artesian aquifers in the New South Wales portion of the Great Artesian Basin. Water bores have been used to demonstrate that the Purlawaugh Beds are characteristically developed in the structural depressions between the ridges of the basement complex (Rade, 1954, p. 81). Commonly the Palaeozoic granites and Palaeozoic rocks of the basement ridges are overlain directly by the Pilliga Beds.

The isopachous map shows a decrease in thickness of the Walloon Coal Measures towards the western margin of the Coonamble Basin. The greatest known thickness was recorded from the south-east of the area under consideration. There 1,291′ of strata are known from Nebea No. 2 Bore, which is located 12 miles north-east of Coonamble. Yowie Bore, 12 miles north-west of Coonamble, revealed a thickness of 1,095′ for the Walloon Coal Measures; Keelendi No. 3 Bore, situated 48 miles south-east of Walgett, penetrated 1,070′ of these sediments, and Combogolong No. 3 Bore, located 18 miles south of Walgett, contained 595′ of the strata.

Near the north-east margin of the basin, the quartz-feldspar-porphyry which forms part of the Palaeozoic basement was first penetrated at 2,647′ in the Gorian Bore, 39 miles east of Walgett. Only 700′ of the Walloon Coal Measures are known from this bore, and the Pilliga Beds directly overlie the basement complex. The base of the formation consists of a 3′ bed of coal, and it is overlain by 347′ of sandstone. Argillaceous intercalations appear towards the top of the formation, and the higher beds consist of sandy shales and shales, which contain beds of sandstone ranging in thickness from 6′ to 17′.

The sediments are more argillaceous in the Tholoo Bore, situated some 9 miles west-south-west of the Gorian Bore and 30 miles east of Walgett. The Tholoo Bore has a total depth of 2,732′; in it the Pilliga Beds again directly overlie the Palaeozoic basement. The lower unit of the formation is formed of 207′ of sandstone; it is overlain by 503′ of intercalated sandy shale and shale. A comparison of the sequences in the Gorian and Tholoo Bores thus reveals that the thickness of the sandy facies of the Pilliga Beds decreases in a westerly direction. This trend is maintained as far west as the Ulumbie Bore, situated 5 miles south-east of Walgett and 26 miles west-south-west of the Tholoo Bore. There the Walloon Coal Measures

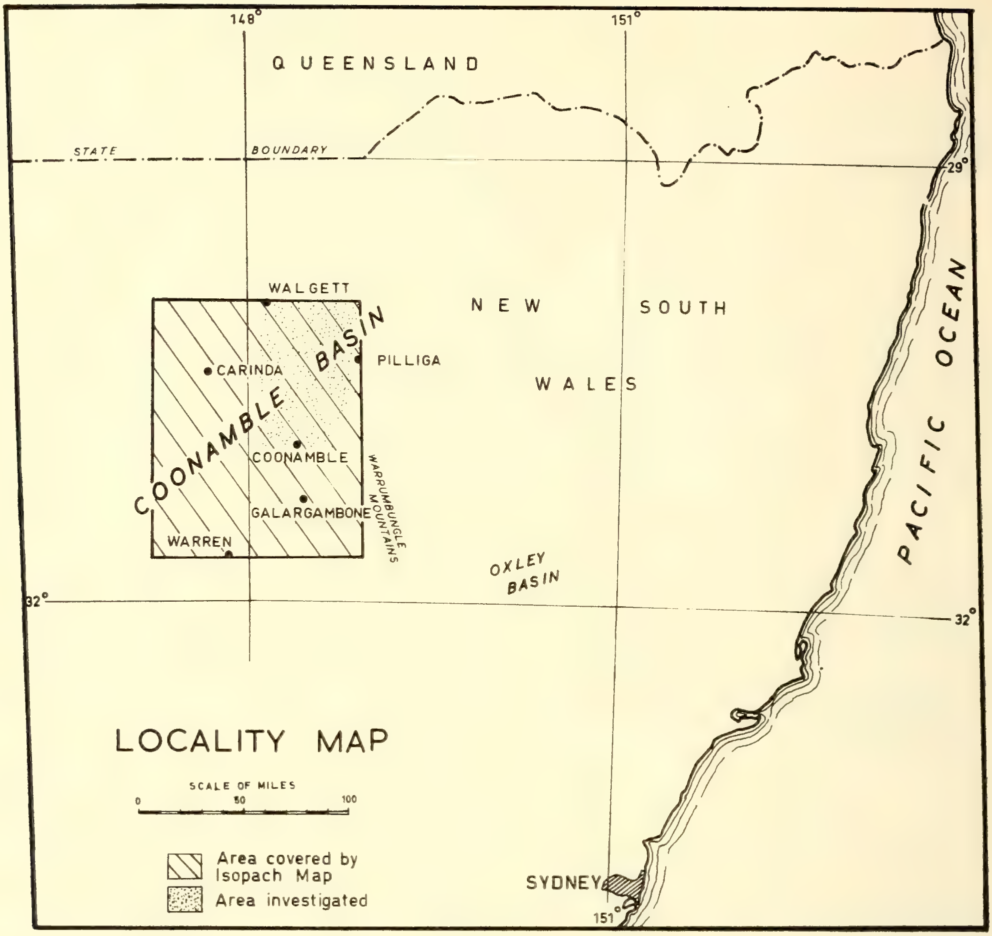

Fig. 1

are 975′ thick ; they are first encountered at a depth of 1,220′, and throughout their entire thickness consist of a rapid alternation of sandstones and shales.

Comparable facies changes are apparent in sections traversing from the south-east to north-west of the area. These sections are available from a study of Nebea No. 2 Bore in the south-east, Wingadee No. 6 Bore, Combogolong No. 3 Bore, and Euroka Bore in the north-west. The facies are somewhat different from those previously considered, for the Pilliga Beds in Nebea No. 2 Bore and Wingadee No. 6 Bore are almost entirely composed of sandstone. Nebea No. 2 Bore has a total depth of 1,934′. Apart from a 23′ bed of gravel, first encountered in the approximate middle of the Pilliga Beds, at 1,213′, the whole of the Walloon Coal Measures in this bore are composed of sandstone. Wingadee No. 6 Bore penetrates 605′ of the Pilliga Beds immediately overlying the basement. No shale intercalations are known in the Pilliga Beds, for the whole of the thickness of the formation is in the sandstone facies. Shaley intercalations in the sandstone appear in the Combogolong No. 3 Bore, which is situated 22 miles north-west of the Wingadee No. 6 Bore. There sandstone beds in the Walloon Coal Measures range in thickness from 17′–125′, whereas the intervening shale beds are from 38′–138′ thick. Similar partially argillaceous facies of the Walloon Coal Measures were encountered in the Euroka Bore, situated eight miles north of Combogolong No. 3 Bore and 11 miles south of Walgett. A 141′ sandstone bed overlies the basement complex and is in turn overlain by 131′ of shale and 62′ of sandstone. Above this are two shale layers, 132′

TABLE I

Bore	Total Depth	Walloon Coal Measures	Purla-waugh Beds	Pilliga Beds	Locality
Wingadee No. 6 ..	2,126′	605′	absent	605′	25 m. N. of Coonamble
Coangra	—	634′	246′	35′ sandstone 127′ shale 226′ sandstone	16 m. S.E. of Walgett
Come by Chance No. 2	—	655′	absent	655′	31 m. S.E. of Walgett
Keelendi No. 2 ..	—	900′	absent	900′	35 m. S.E. of Walgett
Drilldool No. 2 ..	—	775′	80′	695′	49 m. S.E. of Walgett
Milchomi	—	756′	absent	756′	44 m. S.E. of Walgett
Kiewa	—	720′	40′	195′ sandstone 125′ shale 360′ sandstone	36 m. S.E. of Walgett
Coonamble No. 3 ..	2,179′	900′	48′	852′	Coonamble
Yowie	2,350′	1,095′	—	—	12 m. N.W. of Coonamble
Weetaliba	2,073′	744′	absent	744′	20 m. N.E. of Coonamble
Thurn	2,135′	725′	30′	695′	24 m. W.N.W. of Coonamble

and 325′ thick respectively, separated by an 18′ bed of sandstone and overlain by a 30′ sandstone bed.

From these descriptions, it is apparent that sandy facies of the Walloon Coal Measures are dominant along the eastern margin of the Coonamble Basin, especially in the south-east of the area under consideration. Shales are rarely encountered in the south-eastern margin of the area, are sparsely developed in the north-east, but are dominant in the west.

Additional bores which are known to have entered the basement complex may be profitably examined to further elucidate the Walloon Coal Measures sedimentation in the eastern portion of the Coonamble Basin (Table I). A 920′ sequence of shales, claystones, and sandstones of the Walloon Coal Measures was encountered in the Come by Chance No. 1 Bore, situated 22 miles south-east of Walgett. Argillaceous intercalations are ubiquitous in this section, and the thickest sandstone bed measures only 93′. The Pilliga Beds directly overlie the basement in Come by Chance No. 2 Bore.

The Keelendi No. 3 Bore lies near the eastern margin of the Coonamble Basin, and thus the section of the Pilliga Beds which it penetrates is developed in the typical sandy facies. It reaches a total depth of 2,319′. The Pilliga Beds are based by a 95′ bed of sandstone. Overlying this, in turn, are 20′ of white arenaceous claystone, 13′ of sandstone, and a 42′ bed of shale. This sequence is overlain by sandstones containing three shale intercalations. The lowermost of these intercalations is 109′ thick and consists of brown shale. It is overlain by 44′ of sandstone. The middle intercalation is 33′ thick ; it consists of brown shale, and is overlain by 51′ of sandstone. The uppermost intercalation is represented by 20′ of blue shale. A 30′ bed of sandstone forms the top of the sequence.

Keelendi No. 2 Bore penetrates 900′ of the Walloon Coal Measures ; there the Pilliga Beds directly overlie the Palaeozoic basement complex. The sedimentary sequence is initiated by a 347′ bed of porous grey sandstone. Higher beds in the formation are largely composed of shale. They are interbedded with sandstones ranging in thickness from 5′–35′.

The Walloon Coal Measures are 775′ thick in Drilldool No. 2 Bore, where the Pilliga Beds contain, in their upper portion, three intercalations of shale, which correspond to the shale units in Keelendi No. 3 Bore. These shales are from 7′–50′ thick. The Purlawaugh Beds are not developed in the Milchomi Bore. A sandy facies of the Walloon Coal Measures is revealed in the Kiewa Bore. Coonamble No. 3 Bore enters the basement complex at 2,138′. The Purlawaugh Beds overlie the basement. The basal layers of the Pilliga Beds are composed of thinly interbedded sandstones, shales, and sandy shales. Higher beds are formed of sandstone, and the upper layers of the Pilliga Beds consist of sandstone and subordinate thicknesses of shale. The upper beds are composed of a 35′ bed of shale, which is overlain, in turn, by 126′ of sandstone and two thin shale beds separated by an 8′ and a 6′ bed of sandstone near the top of the formation. Quambone No. 2 Bore, situated 20 miles west-north-west of Coonamble, attains a depth of 2,026′. It penetrated a sandy facies of the Walloon Coal Measures, and revealed two intercalations of gravel in the sandstone.

The Yowie Bore is 2,350′ deep. Successively overlying the basement complex are 4′ of fine-grained black sandstone, 20′ of fine-grained black sandstone and shale, 25′ of fine-grained brown sandstone, shale, conglomerate, 30′ of conglomerate, 15′ of shale, 222′ of sandstone, and 60′ of conglomerate containing coal beds. Three additional beds of conglomerate appear higher in the Pilliga Beds. The present author (Rade, 1954) has suggested that this sequence is a product of cyclic sedimentation. Yowie Bore is situated on one of the west-north-west-trending Palaeozoic basement ridges which penetrates from the eastern margin into the eastern portion of the Coonamble Basin. Faulted parallel basement ridges are known further to the north, near the eastern margin of the basin (Rade, 1954), and it is possible that the ridge on which Yowie Bore is located partially owes its origin to faulting. The black sandstone bed at the base of the Pilliga Beds in the Yowie Bore is of interest. It is comparable with the carbonaceous seam in contact with granite near the bottom of the Gorian Bore. Both beds point to stagnant conditions at the time of deposition of the basal strata of the Pilliga Beds. However, the 347′ of sandstone overlying the coal in the Gorian Bore attest well aerated conditions, and the absence of any form of cyclic sedimentation. Different conditions prevailed in the vicinity of the basement ridges further to the south of the Gorian Bore. There, saltatory uplift of the basement ridges is assumed to have been responsible for cyclic sedimentation. The faults which border the ridges of Palaeozoic basement complex were initiated in pre-Jurassic times, but were rejuvenated during the Jurassic.

Hollywood No. 1 Bore is 2,065′ deep and is located 26 miles north-east of Coonamble. In it the Pilliga Beds are 727′ thick and consist of sandstones containing a 20′ and a 27′ bed of claystone. The Weetaliba Bore penetrated the basement complex at 2,010′. The Thurn Bore penetrated the Palaeozoic basement complex at 2,118′. Directly overlying the basement complex is 30′ of Purlawaugh Beds. At the base of the Pilliga Beds is an 8′ bed of sandstone. This is successively overlain by a 2′ bed of coal and 189′ of sandstone. The upper portion of the Pilliga Beds consists of interbedded sandstones, sandy grey shales, and white claystones.

Geological Structure

West-north-west-trending ridges in the Palaeozoic basement complex dominate the geological structure of the eastern portion of the Coonamble Basin. Granites and quartz-feldspar-porphyries directly underlie the Pilliga Beds in the north-eastern corner of the map area. Further to the south a granitic basement ridge appears as a structural nose in the Palaeozoic basement contour map published by the author (Rade, 1954, text-fig. 2). The Pilliga Beds overlie granite in Keelendi No. 1 Bore, some 44 miles north-east of Coonamble. To the north-east of this granitic ridge the Purlawaugh Beds appear in Drilldool No. 2 Bore. The next basement nose to the south is found 26 miles north of Coonamble. A structural depression filled with the Purlawaugh Beds exists between these two basement noses. Some 40′ of the Purlawaugh Beds are known from the Kiewa Bore, 48′ are recorded from Coonamble No. 3 Bore, 40′ appear in the Thurn Bore, and they are also present in Quambone No. 4 Bore. The Purlawaugh Beds also overlie the basement complex in the Coangra Bore. The vicinity of this bore is occupied by a deep depression in the surface of the basement complex, with the result that the maximum thickness of 246′ for the Purlawaugh Beds is recorded in this area. The depression is elongate to the south-east and is bordered to the east by a basement ridge.

The isopach map of the Jurassic (Fig. 2) presented in this paper is constructed between the base of the Mesozoic and the upper artesian aquifer of the Blythesdale Group. It shows that the Jurassic sediments are thickest on the eastern side of the map area, i.e. along the western marginal depression of the Eastern Australian Cordillera. This depression can be traced northwards as far as the Gulf of Carpentaria, and southwards beyond the Oxley Basin. Petroleum has been found in this depression in south-eastern Queensland.

Hydrology

The most important artesian aquifers in the Walloon Coal Measures are located in the Pilliga Beds. The upper aquifer generally occurs in the top 100′ of the formation, and it is frequently encountered a few feet below the overlying formation. Such is the case in the Milchomi Bore, where the upper artesian aquifer of the Pilliga Beds is penetrated at the top of the sandy sequence of that formation, at a depth of 1,162′. In those sections of the Pilliga Beds in which the upper 100′ is impervious and does not contain intercalations of porous sandstone, the highest aquifer is frequently much deeper.

The depth of the second main aquifer of the Pilliga Beds is variable, depending on the

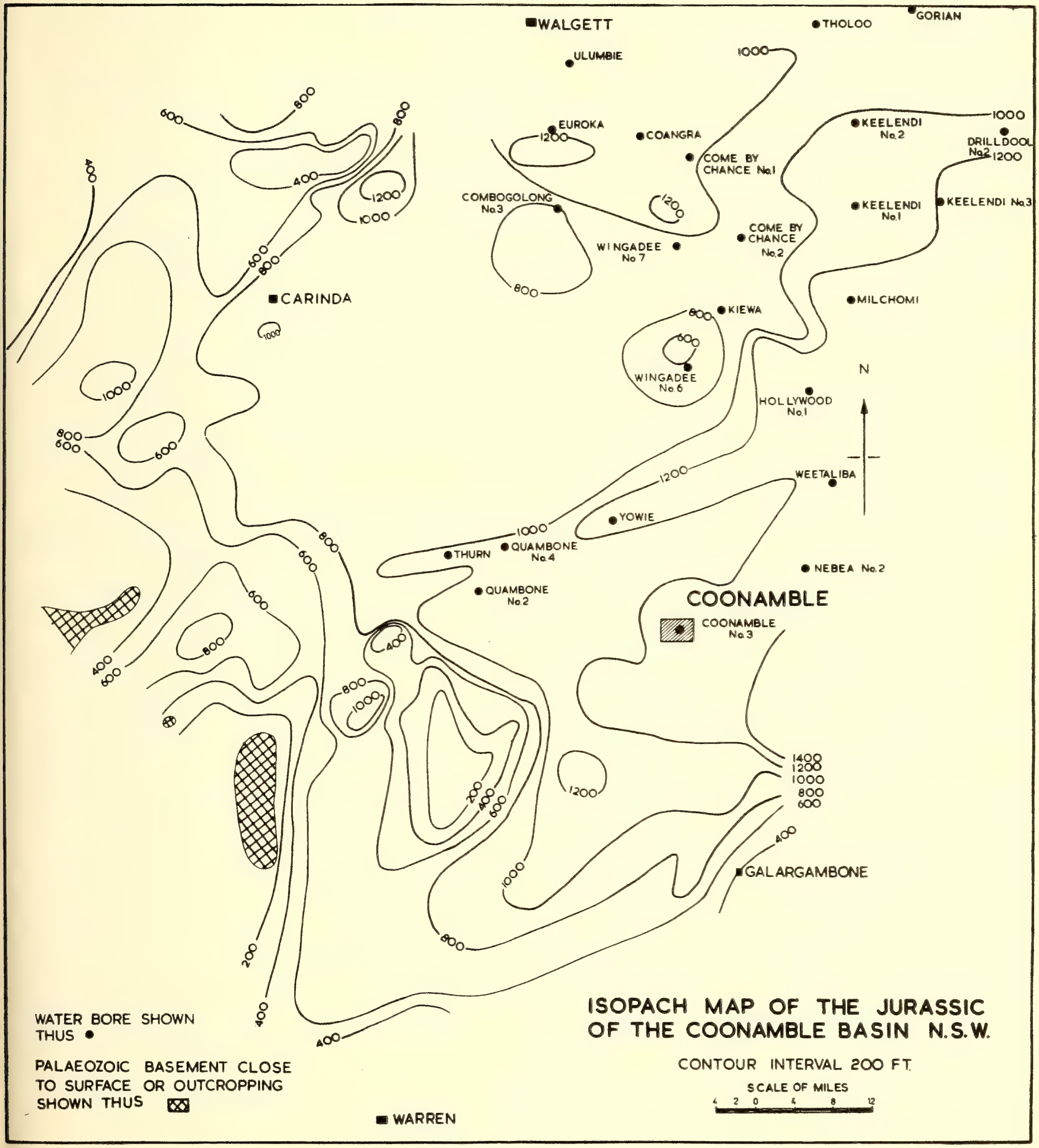
WALGETT
THOLOO
GORIAN
ULUMBIE
EUROKA
COANGRA
COME BY CHANCE No.1
KEELENDI No.2
DRILLDOOL No.2
KEELENDI No.1
KEELENDI No.3
COMBOGOLONG No.3
WINGADEE No.7
COME BY CHANCE No.2
CARINDA
KIEWA
MILCHOMI
WINGADEE No.6
HOLLYWOOD No.1
N
WEETALIBA
YOWIE
THURN
QUAMBONE No.4
QUAMBONE No.2
NEBEA No.2
COONAMBLE
COONAMBLE No.3
GALARGAMBONE
WARREN
WATER BORE SHOWN THUS ●
PALAEOZOIC BASEMENT CLOSE TO SURFACE OR OUTCROPPING SHOWN THUS
ISOPACH MAP OF THE JURASSIC OF THE COONAMBLE BASIN N.S.W.
CONTOUR INTERVAL 200 FT.
SCALE OF MILES

Fig. 2

TABLE II

Bore	Aquifers	Grains of Total Solids per Gallon
Gorian	—	48
Weetaliba	—	26
Quambone No. 2 ..	—	30
Hollywood No. 1 ..	—	42
Wingadee No. 6 ..	—	50
Come by Chance No. 1	—	55
Come by Chance No. 2	1,862′	61
	2,195′	57*
	2,437′	60
Euroka	1,584′	74
	1,938′	62
	2,433′	55
Combogolong No. 3 ..	1,695′ } 1,910′ }	69
	1,985′ } 2,107–2,122′ }	57
	2,343′	58
Coangra	—	74

* When all of the flows are included.

thickness of the impervious strata which separates the two aquifers. Impervious intercalations may be represented by shale. In the Hollywood No. 1 Bore, the first artesian aquifer in the Pilliga Beds was encountered at a depth of 1,265′, and it is separated by impervious shales from the next aquifer, at 1,440′.

The artesian aquifers of the Walloon Coal Measures from 2,478′–2,535′ and at 2,732′ in the Tholoo Bore contain 47 grains of total solids per gallon. Similarly, 48 grains of total solids per gallon were encountered in the water of the Gorian Bore. Both these bores are in the northern portion of the area under study. Only 26 grains of total solids per gallon occur in the Weetaliba Bore, situated near the south-eastern margin of the map area. As is the case for the Weetaliba Bore, the Quambone No. 2 Bore also obtained good water from the main southern intake area, and its total solids content is only 30 grains per gallon. Wingadee No. 6 Bore, which is situated in the middle of the area under consideration, has a total solids content of 50 grains per gallon. The deeper flows in the Euroka Bore contain less dissolved material than those from shallower depths (Table II). Shale is a prominent sediment in the Euroka Bore, and the hole is situated in the part of the Coonamble Basin where "salting" is common in sections of high shale content. A similar picture is obtained for Combogolong No. 3 Bore. The extremely high figure of 74 grains per gallon was obtained for the Coangra Bore. The results of the chemical analysis of the water obtained from the bores can be found in Report of Interstate Conference on Artesian Water (1912), Report on the Second Interstate Conference on Artesian Water (1914), and Report of the Fourth Interstate Conference on Artesian Water (1924).

From the figures given above, it is apparent that when the upper portion of the Pilliga Beds is shaley in nature, then the highest aquifer in the formation is more saline than the lower aquifers. The water with least total solids is encountered in the southern and eastern portions of the Coonamble Basin close to the intake beds.

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On the Gibbs' Phenomenon in n-Dimensional Fourier Transforms

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ABSTRACT—It is shown that with the simple inversion formula, the Hankel transform exhibits a Gibbs' phenomenon at a point of discontinuity of the same magnitude as in the cases of the Finite Fourier and one-dimensional Fourier transforms.

In the case of the n-dimensional Fourier transform we must add reasonably heavy restrictions in order that the simple inversion formula should converge. When we do this we find that this transform will exhibit the Gibbs' phenomenon. In the simplest cases this magnitude will be equal to that in the two transforms mentioned above.

1

The Gibbs' phenomenon was originally discovered in connection with the simple summation of Fourier series. It is discussed thoroughly in Sansone (1960, pp. 141–148). In its simpler aspects it may be described as follows:

Suppose that f is continuous and of bounded variation in a neighbourhood of x_0 except that at x_0 it has a simple jump $h=f(x_0+)-f(x_0-)$ at x_0. Let the Fourier coefficients of f be $\{a_n\}$ and let the Fourier terms be $\{\varphi_n\}$. Now write

$$S_n(x)=\sum_{k=1}^{n} a_n\varphi_n(x).$$

Then as $n\to\infty$, the approximation curves $S_n(x)$ tend to

$$f(x_0+)+h(1/\pi)\left|\int_{\pi}^{\infty} y^{-1}\sin y\,dy\right| \quad \text{as } x\to x_0+$$

and to

$$f(x_0-)-h(1/\pi)\left|\int_{\pi}^{\infty} y^{-1}\sin y\,dy\right| \quad \text{as } x\to x_0-.$$

We can alter the aspect of the phenomenon if we consider it as a feature of the finite Fourier transform. Thus if

$$\begin{aligned} a_n&=T[f(x)], \quad n=1, 2, \ldots \\ &=\int_0^{2\pi} f(x)\varphi_n(x)dx \end{aligned}$$

then the particular inversion formula

$$\begin{aligned} f(x)&=T^{-1}[a_n] \\ &=\sum_{n=1}^{\infty} a_n\varphi_n(x)=\lim_{n\to\infty}\sum_{k=1}^{n} a_n\varphi_n(x) \end{aligned}$$

possesses the Gibbs' phenomenon.

This shows that the phenomenon is a feature of the particular inversion formula chosen for the transform.

2

The one-dimensional Fourier transform for functions in $L^1(-\infty,\infty)$ may be written as

$$F(y)=(2\pi)^{-\frac{1}{2}}\int_{-\infty}^{\infty} e^{iyx}f(x)dx. \tag{2.1}$$

We then consider

$$I(x,R)=(2\pi)^{-\frac{1}{2}}\int_{-R}^{R} e^{-ixy}F(y)dy. \tag{2.2}$$

When $f(t)$ is continuous and of bounded variation in the neighbourhood of x, we know that $\lim_{R\to\infty} I(x,R)=f(x)$.

It is also known that the inversion formula $\lim_{R\to\infty} I(x,R)$ exhibits the Gibbs' phenomenon; see, for example, Papoulis, 1962, p. 30. In order to clarify Section 4, we will include a few remarks on this situation.

It is easy to prove that if $f(t)$ is continuous in an interval $(x-\delta, x+\delta)$ then (2.2) converges uniformly to $f(x)$ in $(x-\frac{1}{2}\delta, x+\frac{1}{2}\delta)$.

We now suppose that $f(t)$ is continuous and of bounded variation in a neighbourhood of x_0 except that it possesses a simple jump h at x_0. We write

$$f(t)=g(t)-p(t)$$

where $p(t)=h,\ x_0-a\leqslant x<x_0$
$\qquad\qquad=0$ otherwise.

Thus $g(t)$ will be continuous in a neighbourhood of x_0.

Substituting $p(t)$ for $f(x)$ in (2.1) and (2.2), we easily find that

$$\begin{aligned} I(x,R)&=(1/\pi)\int_{-\infty}^{\infty}\frac{\sin R(t-x)}{t-x}p(t)dt\\ &=(h/\pi)\int_{x_0-a}^{x_0}\frac{\sin R(t-x)}{t-x}dt.\end{aligned}$$

If we write $x=x_0+q$, then

$$\begin{aligned} I(x,R)&=(h/\pi)\int_{q-a}^{q}\frac{\sin Ru}{u}du\\ &=(h/\pi)\int_{Rq-Ra}^{Rq}\frac{\sin u}{u}du\end{aligned}$$

We now write $Rq=\alpha$, which we assume fixed, then

$$I(x,R)=(h/\pi)\int_{\alpha-Ra}^{\alpha}\frac{\sin u}{u}du.$$

As $R\to\infty$, with $\alpha>0$, we see that

$$I(x,R)\to(h/\pi)\int_{-\infty}^{\alpha}\frac{\sin u}{u}du=h-(h/\pi)\int_{\alpha}^{\infty}\frac{\sin u}{u}du \tag{2.3}$$

and when $\alpha<0$

$$I(x,R)\to(h/\pi)\int_{-\infty}^{\alpha}\frac{\sin u}{u}du=(h/\pi)\int_{|\alpha|}^{\infty}\frac{\sin u}{u}du. \tag{2.4}$$

Both integrals on the right side of each of the last two equations take the maximum values when $\alpha=\pi$.

A limit of the form in (2.3) and (2.4) shows that the Gibbs' phenomenon takes place. The maximum value of the error is found by suitable choice of α. To be more exact we should say that we have shown that the error is at least as great as error found by maximizing the error in (2.3) and (2.4).

3

We now examine the Hankel transform in the form

$$F(y)=\int_0^\infty (yt)^{\frac{1}{2}} J_\nu(yt)f(t)dt \tag{3.1}$$

and the corresponding integral

$$I(x,R)=\int_0^R (xy)^{\frac{1}{2}} J_\nu(xy)F(y)dy. \tag{3.2}$$

The result we require is : If $f(x)$ belongs to $L^1(0,\infty)$ and is continuous and of bounded variation in the interval $[a,b]$, then $I(x,R)$ converges uniformly for all x in $[p,q]$ with $0<a<p<q<b$.

The proof of this theorem follows by trivial modifications of Th. 135 of Titchmarsh (1948, p. 240). The only points worthy of note are that the choice of δ in that proof is made so that $\chi_1(y)$ and $\chi_2(y)$ on p. 241 are uniformly bounded by ε for all x in $[p.q]$ and that the integral on the second line of p. 242 converges uniformly for x in $[p,q]$.

We assume that $f(t)$ and $g(t)$ are defined as in the previous section and that $h(x)$

$$\begin{aligned} p(t)&=ht^{\nu+\frac{1}{2}}/x_0^{\nu+\frac{1}{2}} \text{ for } t<x_0 \\ &=0 \text{ otherwise.} \end{aligned}$$

From equation (4.1) we find that

$$\begin{aligned} H(y)&=\int_0^{x_0} (yt)^{\frac{1}{2}} J_\nu(yt)(ht^{\nu+\frac{1}{2}}/x_0^{\nu+\frac{1}{2}})dt \\ &=hy^{-\frac{1}{2}}x_0^{\frac{1}{2}} J_{\nu+1}(x_0y). \end{aligned}$$

Then

$$\begin{aligned} I(x,R)&=\int_0^R (xy)^{\frac{1}{2}} J_\nu(xy)H(y)dy \\ &=hx_0^{\frac{1}{2}}x^{\frac{1}{2}}\int_0^R J_\nu(xy)J_{\nu+1}(x_0y)dy \\ &=hx_0^{\frac{1}{2}}x^{\frac{1}{2}}\left[\int_0^{\to\infty}-\int_R^{\to\infty}\right] J_\nu(xy)J_{\nu+1}(x_0y)dy \\ &=p(x)-hx_0^{\frac{1}{2}}x^{\frac{1}{2}}\int_R^{\to\infty} J_\nu(xy)J_{\nu+1}(x_0y)dy \qquad x\neq x_0. \end{aligned} \tag{3.3}$$

Now for large R, the second integral can be expressed as

$$I=(2/\pi)\int_R^\infty y^{-1}\cos(x_0y-w)\sin(xy-w)dy+\int_R^\infty 0(y^{-1\frac{1}{2}})dy$$

the second term holding uniformly for x in $x_0-\delta$, $x_0+\delta$ some δ, and where $w=\frac{1}{2}\nu\pi+\frac{1}{4}\pi$. Then

$$I=(1/\pi)\int_R^\infty y^{-1}\sin((x+x_0)y-2w)dy+(1/\pi)\int_R^\infty y^{-1}\sin(x-x_0)ydy+0(R^{-\frac{1}{2}}) \tag{3.4}$$

We now write $x-x_0=q$ and as before make $Rq=\alpha$ (a constant).

The first integral is $O(R^{-1})$, so we make a change of variable in the second integral and obtain

$$I=(1/\pi)\int_\alpha^\infty \frac{\sin y}{y}dy+O(R^{-\frac{1}{2}}) \qquad \text{for } \alpha>0$$

$$=-(1/\pi)\int_{|\alpha|}^\infty \frac{\sin y}{y}dy+O(R^{-\frac{1}{2}}) \qquad \text{for } \alpha<0.$$

Then referring back to the previous section, we note that the Hankel transform with the inversion integral in the form of (3.2) possesses the Gibbs' phenomenon.

When $\nu=m$ or $m+\frac{1}{2}$ for integral m, the Hankel transform can be considered to be the $(2\nu+2)$th dimensional Fourier transform of a radially symmetric function. Thus it will be of interest to examine the k-dimensional Fourier transform to see whether the Gibbs' phenomenon will be displayed in cases when radial symmetry is lacking.

4

Denoting the k-dimensional Cartesian space by E_k, we define the Fourier transform by

$$F(u)=(2\pi)^{-\frac{1}{2}k}\int_{E_k}\exp i(x.u)f(x)dV_x \tag{4.1}$$

where we assume that f belongs to $L^1(E_k)$ and that the symbols u and x denote the vectors $(u_1,\ldots,u_k)$ and $(x_1,\ldots,x_k)$ respectively, while $x.u$ is understood to mean the corresponding scalar product.

We will examine the integral

$$I_R=(2\pi)^{-\frac{1}{2}k}\int_{B_R}\exp[-i(x.u)]F(u)dV_u$$

$$=(2\pi)^{-k}\int_{E_k}f(y)dV_y\int_{B_R}\exp[i(u.(y-x))]dV_u,$$

where B_R is the k-dimensional ball with radius R, that is the set of points in the u-space with $|u|\leqslant R$.

Then changing to polar co-ordinates in k-dimensional space we may simplify I_R to the form

$$I_R=(2\pi)^{-\frac{1}{2}k}\int_{E_k}f(y)dV_y\int_0^R s^{-\frac{1}{2}(k-2)}r^{\frac{1}{2}k}J_{\frac{1}{2}(k-2)}(sr)dr$$

(McLachlan, p. 58 (25)) where r is the radial co-ordinate in u-space and

$$s^2=\sum_{n=1}^{k}(y_n-x_n)^2.$$

Thus

$$I_R=(2\pi)^{-\frac{1}{2}k}\int_{E_k}s^{-\frac{1}{2}k}R^{\frac{1}{2}k}J_{\frac{1}{2}k}(sR)f(y)dV_y$$

We now shift the origin to the point x. The new radial co-ordinate will be s. The spherical co-ordinates with centre x will be s, θ_1, θ_2, . . ., θ_{k-1} and they are connected with the Cartesian co-ordinates with centre x by the formulae

$$x'_1=sC_1=sp_1\,;\quad x'_2=sS_1C_2=sp_2$$
$$x'_3=sS_1S_2C_3=sp_3\ldots$$
$$x'_{k-1}=sS_1S_2\ldots S_{k-2}C_{k-1}=sp_{k-1}\,;\quad x'_k=sS_1S_2\ldots S_{k-2}S_{k-1}=sp_k.$$

with $C_n=\cos\theta_n$ and $S_n=\sin\theta_n$.

(The Jacobian of the system is $s^{k-1}S_1^{k-2}S_2^{k-1}\ldots S_{k-2}^1$).

We may partly complete the integration by writing

$$I_R=\int_0^\infty s^{\frac{1}{2}k-1}R^{\frac{1}{2}k}J_{\frac{1}{2}k}(sR)\,Q(s)ds \tag{4.2}$$

where

$$Q(s)=(2\pi)^{-\frac{1}{2}k}\int_{S_1} f(x_1+sp_1,\ldots,x_k+sp_k)dA \tag{4.3}$$

where S_1 indicates the sphere of radius 1 with centre x, which also may be interpreted as a " solid angle " integral over a sphere of radius s.

Suppose now that $Q(s)=s^2$, $0\leqslant s\leqslant a$ and $=0$ otherwise. Then (McLachlan, p. 158 (22))

$$I_R=a^{\frac{1}{2}k+1}R^{\frac{1}{2}k-1}J_{\frac{1}{2}k+1}(aR)$$

which cannot converge as $R\to\infty$ unless $k=2$ (McLachlan, 1941, p. 158 (13)).

Thus for $k>2$, we cannot expect $\lim\limits_{R\to\infty} I_R$ to converge if $Q(s)$ possesses a jump discontinuity on any sphere with centre x.

Suppose that $k=2$, then

$$Q(s)=(1/2\pi)\int_0^{2\pi} f(x+s\cos\theta,\,y+s\sin\theta)d\theta.$$

Proceeding formally from equation (4.2), we obtain

$$\int_0^\infty R^1J_1(sR)\,Q(s)ds=-\Big[J_0(sR)\,Q(s)\Big]_0^\infty+\int_0^\infty J_0(sR)\,Q'(s)ds$$

If we suppose that $Q(0+)$ exists, $Q(s)\to 0$ as $s\to\infty$ and that $Q'(s)$ belongs to $L^1(0,\infty)$ then we may take the limit to obtain

$$\lim_{R\to\infty}\int_0^\infty R^1J_1(sR)\,Q(s)ds=Q(0+).$$

We may go a little further when $k=2$ by supposing that $Q(s)$ possesses a finite number of jumps but is otherwise absolutely continuous. If $Q(s)$ possesses successive jumps at $s=a$ and $s=b$, then

$$\int_a^b R^1J_1(sR)\,Q(s)ds=-\Big[J_0(sR)\,Q(s)\Big]_a^b+\int_a^b J_0(sR)\,Q'(s)ds$$

where all the terms on the right will vanish as $R\to\infty$.

We return to the general case and write as is usually done $\nu=\frac{1}{2}(k-2)$, then

$$I_R=\int_0^\infty R^{1+\nu}s^\nu J_{1+\nu}(sR)\,Q(s)ds$$
$$=\int_0^\infty R^{1+\nu}2^\nu u^{\frac{1}{2}(\nu-1)}J_{1+\nu}(2Ru^{\frac{1}{2}})\,Q(2u^{\frac{1}{2}})du$$

(by change of variable)

$$=\int_0^\infty 2^\nu R^{2\nu+2}(R^2u)^{-\frac{1}{2}(1+\nu)}J_{1+\nu}(2Ru^{\frac{1}{2}})[u^\nu Q(2u^{\frac{1}{2}})]du.$$

We now proceed formally using integration by parts and McLachlan, p. 158 (21) :

$$\begin{aligned}I_R=&-2^\nu R^{2\nu}\Big[(R^2u)^{-\frac{1}{2}\nu}J^\nu(2Ru^{\frac{1}{2}})[u^\nu Q(2u^{\frac{1}{2}})]\Big]_0^\infty\\ &-2^\nu R^{2\nu-2}\Big[(R^2u)^{-\frac{1}{2}(\nu-1)}J_{\nu-1}(2Ru^{\frac{1}{2}})[u^\nu Q(2u^{\frac{1}{2}})]^{(1)}\Big]_0^\infty\\ &\quad\cdot\qquad\cdot\qquad\cdot\qquad\cdot\qquad\cdot\\ &-2^\nu R^{2\nu-2n}\Big[(R^2u)^{-\frac{1}{2}(\nu-n)}J_{\nu-n}(2Ru^{\frac{1}{2}})[u^\nu Q(2u^{\frac{1}{2}})]^{(n)}\Big]_0^\infty\\ &+2^\nu R^{2\nu-2n}\int_0^\infty(R^2u)^{-\frac{1}{2}(\nu-n)}J_{\nu-n}(2Ru^{\frac{1}{2}})[u^\nu Q(2u^{\frac{1}{2}})]^{(n+1)}du,\end{aligned}\tag{4.4}$$

where the indices indicate derivatives with regard to u.

We note that we have assumed that $f(x)$ belonged to $L^1(E_k)$. Thus with a change of origin $\int_0^\infty s^{k-1}\,|\,Q(s)\,|\,ds$ is finite for all x. By a further change of variables $\int_0^\infty u^\nu\,|\,Q(2u^{\frac{1}{2}})\,|\,du$ is finite and can be seen to be uniformly bounded for all x.

These assumptions will not be sufficient to ensure the validity of all the steps in equation (4.4) so we will assume that $Q^{(p)}(0+)$, for $0\leqslant p\leqslant n$, will be finite. We will also assume that $Q^{(p)}s)$ will be sufficiently small for large s for all the integrated terms in equation (4.4) to vanish.

We consider first the situation when $\nu=m$ (an integer) and we will put $n=m-1$. Thus

$$I_R=2^mR\int_0^\infty u^{-\frac{1}{2}}J_1(2Ru^{\frac{1}{2}})[u^mQ(2u^{\frac{1}{2}})]^{(m)}du\tag{4.5a}$$

Assuming that $[u^mQ(2u^{\frac{1}{2}})]^{(m)}$ is sectionally absolutely continuous with a finite number of jumps, and that $Q^{(m)}(0+)$ exists and further that $[u^mQ(2u^{\frac{1}{2}})]^{(m)}$ is sufficiently small for large u, we will carry equation (4.5) one step further.

$$\begin{aligned}I_R=&-2^m\sum_{p=1}^{q-1}[J_0(2Ru^{\frac{1}{2}})[u^mQ(2u^{\frac{1}{2}})]^{(m)}]_{a_p}^{a_{p+1}}\\ &+2^mJ_0(2Ra_q^{\frac{1}{2}})[u^mQ(2u^{\frac{1}{2}})]^{(m)}_{u=a_q}\\ &+2^m\int_0^\infty J_0(2Ru^{\frac{1}{2}})[u^mQ(2u^{\frac{1}{2}})]^{(m+1)}du\end{aligned}\tag{4.5b}$$

where $a_0=0$ and the q jumps of $[u^mQ(2u^{\frac{1}{2}})]^{(m)}$ occur at a_p $(p=1\,.\,.\,.,q)$.

Thus taking the limit $R\to\infty$, we find that

$$\begin{aligned}\lim_{R\to\infty}I_R=&2^m\Gamma(m+1)\,Q(0+)\\ &+\lim_{R\to\infty}2^m\int_0^\infty J_0(2Ru^{\frac{1}{2}})[u^mQ(2u^{\frac{1}{2}})]^{(m+1)}du.\end{aligned}\tag{4.6a}$$

In order to ensure the vanishing of the integral in (5.6a) it will suffice if we assume that $u^{-\frac{1}{2}}[u^m Q(2u^{\frac{1}{2}})]^{(m+1)}$ belongs to $L^1(1,\infty)$ and that $[u^m Q(2u^{\frac{1}{2}})]^{(m+1)}$ belongs to $L^1(0,1)$. Then

$$\lim_{R\to\infty} I_R = 2^m \Gamma(m+1) Q(0+). \tag{4.6b}$$

Now when $\nu = m+\frac{1}{2}$, we make corresponding assumptions on $[u^{m+\frac{1}{2}}Q(2u^{\frac{1}{2}})]^{(n)}$. All integrated terms in equation (5.4) will vanish. We are then left with

$$\begin{aligned} I_R &= 2^{m+\frac{1}{2}} R^{\frac{1}{2}} \int_0^\infty u^{-\frac{1}{4}} J_{\frac{1}{2}}(2Ru^{\frac{1}{2}})[u^{m+\frac{1}{2}}Q(2u^{\frac{1}{2}})]^{(m+1)} du \\ &= (2^{m+\frac{1}{2}}/\Gamma(\tfrac{1}{2})) \int_0^\infty u^{-\frac{1}{2}} \sin 2Ru^{\frac{1}{2}}\, [u^{m+\frac{1}{2}}Q(2u^{\frac{1}{2}})]^{(m+1)} du. \end{aligned} \tag{4.7a}$$

The limit $R\to\infty$ in equation (4.7a) can be evaluated by the use of Fourier's single integral theorem (Titchmarsh, Th. 12, p. 25).

To be able to apply this theorem we must be assured that $[u^{m+\frac{1}{2}}Q(2u^{\frac{1}{2}})]^{(m+1)}$ belongs to $L^1(0,\infty)$ and that $u^{\frac{1}{2}}[u^{m+\frac{1}{2}}Q(2u^{\frac{1}{2}})]^{(m+1)}$ is of bounded variation near the origin (and continuous). The result will be

$$\begin{aligned} \lim_{R\to\infty} I_R &= 2^{m+\frac{1}{2}}\Gamma(\tfrac{1}{2}) \lim_{u\to 0+} u^{\frac{1}{2}}[u^{m+\frac{1}{2}}Q(2u^{\frac{1}{2}})]^{(m+1)} \\ &= 2^{m+\frac{1}{2}}\Gamma(m+1\tfrac{1}{2}) Q(0+). \end{aligned} \tag{4.7b}$$

We recall that the " area " of the surface of the k-sphere (i.e. $k-1$ volume) with radius unity is $2\pi^{\frac{1}{2}k}/\Gamma(\frac{1}{2}k) = 2\pi^{\nu+1}/\Gamma(\nu+1)$. Thus both the equations (4.6b) and (4.7a) may be interpreted to be

$$\lim_{R\to} I_R = \lim_{s\to 0+} \frac{\int_{S_1} f(x_1+sp_1, \ldots, x_k+sp_k) dA}{A_1} \tag{4.8a}$$

where A_1 is the area of the unit sphere.

When f is continuous, the limit in (4.8a) reduces to $f(x)$ as expected.

We now assume that x is restricted to lie in a compact region C of the k-dimensional space E_k. We wish to add restrictions on $Q(s)$ which will ensure the uniform convergence of the limits in equations (4.6b) and (4.7b). It is difficult to decide what are the best conditions to impose, but it is obvious that when $\nu = m$, the following will be sufficient : For all x in C

(i) $Q(s)$ is continuous ;

(ii) there exists a b so that $\int_b^\infty |\, u^{-\frac{1}{2}}[u^m Q(2u^{\frac{1}{2}})]^{(m+1)} \,|\, du$ and $\int_0^b |\, [u^m Q(2u^{\frac{1}{2}})]^{(m+1)} \,|\, du$ are uniformly bounded ;

(iii) $[u^m Q(2u^{\frac{1}{2}})]^{(m)}$ is bounded uniformly.

Here (i) is necessary to ensure the existence of $Q(0+)$. The condition (ii) is sufficient for the vanishing of the summation terms in equation (4.5b). Condition (ii) is sufficient for the uniform vanishing of the integral in equation (4.5b).

When $\nu = m+\frac{1}{2}$, the limit $Q(0+)$ does not appear explicitly so it is to be expected that the conditions imposed will be considerably different.

Write $P(s) = u^{m+\frac{1}{2}}[Q(2u^{\frac{1}{2}})]^{(m+1)}$, $s = \frac{1}{4}u^2$, so that

$$\int_0^\infty u^{-\frac{1}{2}} \sin 2Ru^{\frac{1}{2}} [u^{m+\frac{1}{2}}Q(2u^{\frac{1}{2}})]^{(m+1)} du = \int_0^\infty \sin RsP(s) ds.$$

Then for x in C we will assume that

(i) $\int_0^\infty |P(s)|\,ds$ converges uniformly at the upper limit.
(ii) The variation of $sP(s)$ in $[0,b]$ for every fixed b is uniformly bounded.
(iii) $sP(s)$ is continuous in $[0,c]\times C$ for some $c>0$.

We give an outline of the proof of the uniform convergence of the limit.
Write

$$\int_0^\infty \sin Rs\, P(s)ds = \int_0^c + \int_c^b + \int_b^\infty \sin Rs\, P(s)ds.$$

Then choose b so that $\int_b^\infty |P(s)|\,ds<\varepsilon$.

Write $sP(s)=F(s)-G(s)$ in which $F(s)$ and $G(s)$ are positive monotone increasing and uniformly bounded in $[0,b]$.

$$\int_c^b F(s) \sin Rs/s.ds = F(b)\int_k^b \sin Rs/s.ds,\ c\leqslant k<b.$$
$$\to 0 \text{ uniformly as } R\to\infty.$$

A similar treatment applies to $G(s)$.

$$\int_0^c F(s) \sin Rs/s\, ds = F(0+)\int_0^c \sin Rs/s\, ds + \int_\eta^c (F(s)-F(0+))\sin Rs/s\, ds$$
$$+\int_0^\eta (F(s)-F(0+)) \sin Rs/s\, ds.$$

The choice of η so that $|F(s)-F(0+)|<\varepsilon$ uniformly will then show that

$$\lim_{R\to\infty}\int_0^\infty P(s) \sin Rs/s\, ds = \tfrac{1}{2}\pi \lim_{s\to 0+} sP(s)$$
$$= \lim_{u\to 0+} u^{\frac{1}{2}}[u^{m+\frac{1}{2}}Q(2u^{\frac{1}{2}})]^{(m+1)}$$

the convergence being uniform.

5

Suppose that P is a point situated a distance x from a plane, and lying in a region A which crosses the plane. Suppose also that f is defined so that appropriate conditions in Section 4 hold. Further, let $f=1$ on the side of the plane remote from P and $=0$ on the side of the plane including P, in a sufficiently great region. Then for sufficiently small s we see that $Q(s)=0$ on the side of the plane including P and on the remote side

$$Q(s)=(2\pi)^{-\frac{1}{2}k}2\pi\int_0^{\cos^{-1}x/s} S_1^{k-2}d\theta_1\int_0^\pi\ldots\int_0^\pi S_2^{k-3}\ldots S_{k-2}d\theta_2\ldots d\theta_{k-2}$$
$$=(2^{-\frac{1}{2}k+1}/\Gamma(\tfrac{1}{2}(k-1))\Gamma(\tfrac{1}{2})\int_0^{\cos^{-1}x/s} S_1^{k-2}d\theta_1.$$

Again writing $\nu=\frac{1}{2}(k-2)$ and making some simplification, we obtain

$$Q(2u^{\frac{1}{2}})=(2^{-\nu-1}/\Gamma(\nu+\tfrac{1}{2})\Gamma(\tfrac{1}{2}))\int_{x^2/4u}^1 (1-t)^{\nu-\frac{1}{2}}t^{-\frac{1}{2}}dt$$

and with a further change of variables

$$u^{\nu}Q(2u^{\frac{1}{2}})=(2^{-3\nu-1}/\Gamma(\nu+\tfrac{1}{2})\Gamma(\tfrac{1}{2}))\int_{x^2}^{4u}(4u-z)^{\nu-\frac{1}{2}}z^{-\frac{1}{2}}dz. \tag{5.1}$$

Suppose that $\nu=m$ an integer. Then

$$\begin{aligned}[u^m Q(2u^{\frac{1}{2}})]^{(m)}&=2^{-m-1}\pi^{-1}\int_{x^2}^{4u}(4u-z)^{-\frac{1}{2}}z^{-\frac{1}{2}}dz\\ &=2^{-m}\pi^{-1}\cos^{-1}(x^2/2u^{\frac{1}{2}}), \qquad u>4x^2,\\ &=0, \qquad u<4x^2.\end{aligned}$$

Further

$$[u^m Q(2u^{\frac{1}{2}})]^{(m+1)}=\pi^{-1}2^{-m-1}xu^{-1}(4u-x^2)^{-\frac{1}{2}} \quad u>4x^2.$$

The corresponding to equation (4.6a) we obtain

$$\begin{aligned}I_R&=(1/2\pi)\int_{\frac{1}{4}x^2}^{\frac{1}{4}b^2}J_0(2Ru^{\frac{1}{2}})xu^{-1}(4u-x^2)^{-\frac{1}{2}}du\\ &=(1/\pi)\int_x^b J_0(Rs)xs^{-1}(s^2-x^2)^{-\frac{1}{2}}ds\\ &=(1/\pi)\int_{Rx}^{Rb}J_0(p)p^{-1}(p^2-R^2x^2)^{-\frac{1}{2}}Rx\,ds\end{aligned}$$

If we now put $Rx=\alpha$ (a constant), we find that

$$\begin{aligned}\lim_{R\to\infty} I_R&=(1/\pi)\int_{\alpha}^{\infty}\alpha J_0(p)p^{-1}(p^2-\alpha^2)^{-\frac{1}{2}}dp\\ &=+(1/\pi)\int_{\alpha}^{\infty}\sin y/y\,dy\end{aligned} \tag{5.2}$$

(using Erdelyi, 1954, p. 18 (5) somewhat modified).

This result shows that the situation exhibits the Gibbs' phenomenon.

If $\nu=m+\frac{1}{2}$, m an integer

$$\begin{aligned}[u^{m+\frac{1}{2}}Q(2u^{\frac{1}{2}})]^{(m)}&=(2^{-m-1\frac{1}{2}}/\Gamma(\tfrac{1}{2})).(2u^{\frac{1}{2}}-x), \qquad u>\tfrac{1}{4}x^2\\ &=0, \qquad u<\tfrac{1}{4}x^2\\ [u^{m+\frac{1}{2}}Q(2u^{\frac{1}{2}})]^{(m+1)}&=u^{-\frac{1}{2}}/2^{m+1\frac{1}{2}}\,\Gamma(\tfrac{1}{2}) \qquad u>\tfrac{1}{4}x^2\\ &=0 \qquad u<\tfrac{1}{4}x^2.\end{aligned}$$

Thus from (4.7a) suitably modified

$$\begin{aligned}I_R&=(1/2\pi)\int_{\frac{1}{4}x^2}^{\frac{1}{4}b^2}u^{-1}\sin 2Ru^{\frac{1}{2}}du\\ &=(1/\pi)\int_{Rx}^{Rb}p^{-1}\sin p\,dp\end{aligned}$$

Thus

$$\lim_{R\to\infty} I_R=(1/\pi)\int_{\alpha}^{\infty}p^{-1}\sin p\,dp \qquad Rx=\alpha.$$

In other words the expected Gibbs' phenomenon takes place.

6

When f is not a constant on the side of the plane remote from P in the situation envisaged in Section 5, we may then write

$$Q(s)=\int_0^{\cos^{-1} x/s} S_1^{k-2}F(s,\theta_1)d\theta_1 \tag{6.1}$$

where now

$$F(s,\theta_1)=(2\pi)^{-\frac{1}{2}k}\int_0^{2\pi}\int_0^{\pi}\cdots\int_0^{\pi} S_2^{k-3},\ldots S_{k-2}f(s,\theta_1,\ldots\theta_{k-1})d\theta_2\ldots d\theta_{k-1}$$

With the same change of variables as before

$$u^{\nu}Q(2u^{\frac{1}{2}})=2^{-2\nu-1}\int_{x^2}^{4u}(4u-z)^{-\frac{1}{2}}z^{-\frac{1}{2}}F(2u^{\frac{1}{2}},\cos^{-1}z^{\frac{1}{2}}/2u^{\frac{1}{2}})dz$$
$$=2^{-2\nu}\int_x^{2u^{\frac{1}{2}}}(4u-t^2)^{-\frac{1}{2}}F(2u^{\frac{1}{2}},\cos^{-1}t/2u^{\frac{1}{2}})dt.$$

We will assume that $F(s,\theta)$ has sufficient bounded derivatives $\partial^{a+b}/\partial s^a\partial\theta^b=F_{a,b}(s,\theta)$. For us to proceed at least formally.

Suppose that $\nu=m$ an integer, then

$$I_R=2^m\int_{\frac{1}{4}x^2}^{\frac{1}{4}b^2} J_0(2Ru^{\frac{1}{2}})du\,2^{-2m}\partial^{m+1}/\partial u^{m+1}\int_x^{2u^{\frac{1}{2}}}(4u-t^2)^{m-1}F(2u^{\frac{1}{2}},\cos^{-1}t/2u^{\frac{1}{2}})dt$$

and after putting $t=w/R$ and $u=v/R^2$

$$I_R=2^{-m}\int_{\frac{1}{4}\alpha^2}^{\frac{1}{4}R^2b^2} J_0(2v^{\frac{1}{2}})dv\,\partial^{m+1}/v\partial^{m+1}\int_\alpha^{2v^{\frac{1}{2}}}(4v-w^2)^{m-\frac{1}{2}}F(2v^{\frac{1}{2}}/R,\cos^{-1}w/2v^{\frac{1}{2}})dw. \tag{6.2}$$

If we expand the derivative into the sum of its components by Leibniz's Theorem we can show that all terms involving $F_{a,b}$ with $a>0$ will be $O(R^{-\frac{1}{2}})$ as $R\to\infty$. Otherwise proceeding formally, we obtain

$$\lim_{R\to\infty} I_R=2^{-m}\int_{\frac{1}{4}\alpha^2}^{\infty} J_0(2v^{\frac{1}{2}})dv\,\partial^{m+1}/\partial v^{m+1}\int_\alpha^{2v^{\frac{1}{2}}}(4v-w^2)^{m-\frac{1}{2}}F(0+,\cos^{-1}w/2v^{\frac{1}{2}})dw. \tag{6.3}$$

If we restrict the case to two dimensions, $k=2$, i.e. $m=0$, we obtain

$$\lim_{R\to\infty} I_R=\int_{\frac{1}{4}\alpha^2}^{+\infty} J_0(2v^{\frac{1}{2}})dv\,\partial/\partial v\int_\alpha^{2v^{\frac{1}{2}}}(4v-w^2)^{-\frac{1}{2}}F(0+,\cos^{-1}w/2v^{\frac{1}{2}})dw$$
$$=\int_{\frac{1}{4}\alpha^2}^{\infty} J_0(2v^{\frac{1}{2}})dv\,\partial/\partial v\int_{\alpha/2v^{\frac{1}{2}}}^{1}(1-t^2)^{-\frac{1}{2}}F(0+,\cos^{-1}t)dt$$
$$=\int_{\frac{1}{4}\alpha^2}^{\infty}\tfrac{1}{2}(\alpha/v)(4v-\alpha^2)^{-\frac{1}{2}}J_0(2v^{\frac{1}{2}})F(0+,\cos^{-1}\alpha/2v^{\frac{1}{2}})dv$$
$$=\int_\alpha^{\infty}(\alpha/s)(s^2-\alpha^2)^{-\frac{1}{2}}J_0(s)F(0+,\cos^{-1}\alpha/s)ds. \tag{6.4}$$

In the case of four dimensions $k=4$, $\nu=1$ a similar reduction gives

$$\lim_{R\to\infty} I_R=\int_\alpha^\infty \frac{J_0(s)}{4(s^2-\alpha^2)^{\frac{1}{2}}s} F(0+, \cos^{-1}\alpha/s)ds$$

$$+\int_\alpha^\infty (\alpha^2-2s^3)J_0(s)F_{0,1}(0+, \cos^{-1}\alpha/s)ds. \tag{6.5}$$

When $\nu=m+\frac{1}{2}$, we write

$$u^{m+\frac{1}{2}}Q(2u^{\frac{1}{2}})=2^{-2m-1}\int_x^{2u^{\frac{1}{2}}} (4u-t^2)^m F(2u^{\frac{1}{2}}, \cos^{-1} t/2u^{\frac{1}{2}})dt.$$

As mentioned above, when we examine

$$\int_{\frac{1}{4}x^2}^{\frac{1}{4}b^2} u^{-\frac{1}{2}} \sin 2Ru^{\frac{1}{2}}[u^{m+\frac{1}{2}}Q(2u^{\frac{1}{2}})]^{(m+1)}du$$

we will find that the terms in the expansion of $[u^{m+\frac{1}{2}}Q(2u^{\frac{1}{2}})]^{(m+1)}$ which involve $F_{a,b}$ with $a>0$ will contribute nothing to the limit.

The limit result will be

$$\lim_{R\to\infty} I_R=2^{-m-\frac{1}{2}}/\Gamma(\tfrac{1}{2})\int_{\frac{1}{4}\alpha^2}^\infty \frac{\sin 2v^{\frac{1}{2}}}{v^{\frac{1}{2}}}dv\left(\frac{d}{dv}\right)^{m+1}\int_\alpha^{2v^{\frac{1}{2}}} (4v-w^2)^m F(0+, \cos^{-1} w/2u^{\frac{1}{2}})dw.$$

In the particular case when $k=3$, $m=0$ we find that

$$\lim_{R\to\infty} I_R=(1/(2\pi)^{\frac{1}{2}})\int_{\frac{1}{4}\alpha^2}^\infty \frac{\sin 2v^{\frac{1}{2}}}{v^{\frac{1}{2}}}dv\frac{d}{dv}\left[(2v^{\frac{1}{2}})\int_{\alpha/2v^{\frac{1}{2}}}^1 F(0+, \cos^{-1} t)dt\right]$$

$$=(1/(2\pi)^{\frac{1}{2}})\int_\alpha^\infty \sin s\left[\frac{2}{s}\int_{\alpha/s}^1 F(0, \cos^{-1} t)dt+\frac{2}{s^2}F(0+, \cos^{-1}\alpha/s)\right]ds,$$

which is easily seen will reduce to our previous result if $F(s,\theta)$ is a constant.

In the case $k=5$, $m=1$ the limit can be expressed in the form

$$\lim_{R\to} I_R=\left(\frac{1}{2\pi}\right)^{\frac{1}{2}}\int_\alpha^\infty \sin s\left[\frac{6}{s}\int_{\alpha/s}^1 (1-t^2)F(0+, \cos^{-1} t)dt+\frac{6\alpha}{s^2}-\frac{2\alpha_3}{s^4}F(0+, \cos^{-1}\alpha/s)\right]ds.$$

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Lower Cretaceous Sporomorphs from the Northern Part of the Clarence Basin, New South Wales

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Abstract—Preliminary results of spore analysis of some soft coal seams from the northern part of the Clarence Basin are given. Eighteen species were identified, four including the stratigraphically important *Perotrilites striatus* Cookson and Dettmann, confined to the Lower Cretaceous. It is concluded that the upper part of the Walloon Series in the northern part of the Clarence Basin is Lower Cretaceous.

Introduction

In 1961 samples of soft coals were collected from the upper part of the grey shales of the Walloon Series at many localities in the northern part of the Clarence Basin. At that time it was believed that the Walloon Series was of Jurassic age and the Cretaceous began with the deposition of the overlying Kangaroo Sandstone. Preliminary work on samples from near Old Bonalbo (6½ miles north-east of Old Bonalbo), the upper part of a large quarry near Bexhill and from Nimbin has shown them to contain spores not older than the Lower Cretaceous, implying that the upper part of the Walloon Series in this area is Lower Cretaceous. These results are being published before completion of work on the remaining localities because they may have some bearing on the search for oil in this part of Australia.

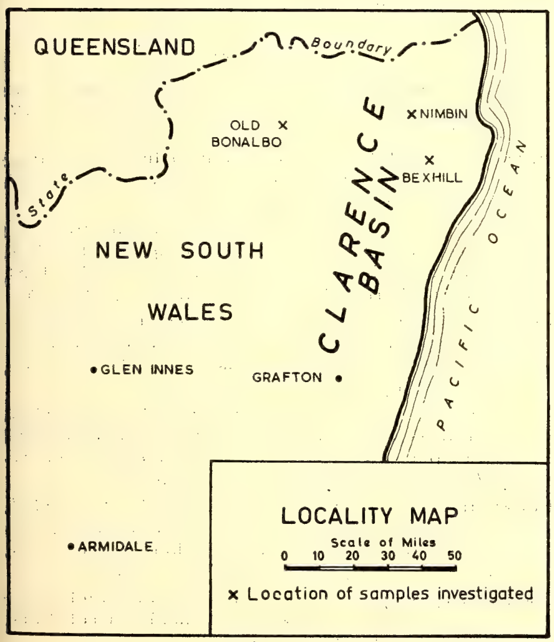

Fig. 1

Distribution of Sporomorphs

	Nimbin	Bexhill	Old Bonalbo
Sphagnumsporites australis (Cookson) Potonié			+
Lycopodiumsporites austroclavatidites Cookson	+		
Faveosporites canalis Balme ..	+		
Cicatricosisporites cooksonii Balme	+		
Gleicheniidites cf. *G. circinidites* Cookson		+	
Osmundacidites comaumensis Cookson	+		
Dictyotosporites complex Cookson and Dettmann		+	
Cingulatisporites floridus Balme ..	+	+	
Cingulatisporites paradoxus Cookson and Dettmann	+		
Entylissa magna de Jersey ..	+		
Araucariacites australis Cookson..	+		
Inaperturopollenites limbatus Balme	+		
Zonalapollenites dampieri Balme	+	+	
Zonalapollenites trilobatus Balme..	+		
Zonalapollenites segmentatus Balme	+		
Perotrilites striatus Cookson and Dettmann	+	+	
Balmeisporites glenelgensis Cookson and Dettmann	+		
Punctatisporites minimus de Jersey			+

Sphagnumsporites australis (Cookson) Potonié is one of the commoner types in the Tertiary lignites of the Kerguelen Archipelago (Cookson, 1947, p. 136) and occurs in the Comaum bore, South Australia (Cookson, 1953, p. 463). According to Balme (1957, p. 16) *Lycopodiumsporites austroclavatidites* Cookson is common in the Upper Jurassic and Lower Cretaceous

of Western Australia. Cookson (1953, p. 469) described it from the Comaum bore, South Australia, and emphasized its affinities with *Lycopodium clavatum* Knox. Balme (1957, p. 17) states that *Faveosporites canalis* Balme is common in the Donnybrook Sandstone at Murphy's Shaft near Donnybrook in the Perth Basin, but only occasional specimens have been found elsewhere. Balme (1957, p. 19) described *Cicatricosisporites cooksonii* Balme from the Birdrong Formation, Carnarvon Basin, W.A., ? Neocomian—Lower Aptian. It is common in the Upper Jurassic and Lower Cretaceous of Western Australia and in the Albian of Queensland. It ranges from Lower Callovian to Upper Albian. *Gleicheniidites* cf. *G. circinidites* Cookson is similar to those described by Balme (1957, p. 23) from Upper Jurassic to Lower Cretaceous rocks from Western Australia, being characteristically smaller than Cookson's species.

Osmundacidites comaumensis Cookson is one of the commonest sporomorphs in the Comaum clays (Cookson, 1953, p. 471). In eastern Australia *Dictyotosporites complex* Cookson and Dettmann is restricted to Lower Cretaceous (Neocomian—Aptian) sediments (Cookson and Dettmann, 1958*b*, p. 108) ; in Western Australia it occurs also in the uppermost Jurassic. Cookson and Dettmann (1958*b*, p. 108) state : " *Perotrilites striatus* has a wide geographical distribution in the eastern Australian region but appears to have a restricted geological range. So far all the deposits in which it has been found are Lower Cretaceous and mostly Albian." Cookson and Dettmann (1958*a*, p. 43) described *Balmeisporites glenelgensis* Cookson and Dettmann from between 6,485 and 6,487 feet in the Nelson bore, parish of Glenelg, Victoria ; according to Baker and Cookson (1955) these sediments are Upper Cretaceous. *Cingulatisporites paradoxus* Cookson and Dettmann is a useful index fossil, being restricted to sediments of Albian to Aptian age (Cookson and Dettmann, 1958*b*, p. 111). Balme (1957, p. 26) described *Cingulatisporites floridus* Balme from the Strathalbyn Sandstone near Gingin, Perth, Western Australia. *Entylissa magna* de Jersey appears to be similar to that described by de Jersey (1960, p. 9) from the Rosewood coalfield of Queensland.

Araucariacites australis Cookson is very common in material from the northern part of the Clarence Basin. Balme (1957, p. 31) records *Inaperturopollenites limbatus* Balme from the Perth Basin and states that it has not been found in any samples known with certainty to be Jurassic. *Zonalapollenites dampieri* Balme is important and common in the Mesozoic, e.g. Bajocian, Upper Jurassic and Lower Cretaceous, of Western Australia (Balme, 1957, p. 32). De Jersey (1960, p. 10) describes it from the Rosewood coalfield of Queensland, and it has also been found in the Eocene of the Perth area and in Aptian–Albian deposits in New Guinea. *Zonalapollenites trilobatus* Balme is confined to the Upper Jurassic and Lower Cretaceous. *Zonalapollenites segmentatus* Balme was very rare in the material examined. Balme (1957, p. 33) described it as fairly common in the Lower Jurassic Cockleshell Gully Sandstone of the Hill River–Jurien Bay area, Perth Basin, but very rare elsewhere. De Jersey (1960, p. 11) recorded it from the Rosewood coalfield, Queensland, which is thought to be Lower Jurassic.

Of the 18 sporomorphs identified, 12 are of stratigraphic importance ; eight of them occur in Upper Jurassic and Lower Cretaceous sediments, and four are found only in the Lower Cretaceous. Of the latter the most important are *Perotrilites striatus* Cookson and Dettmann, which has a very limited time range, and *Balmeisporites glenelgensis* Cookson and Dettmann, which was found in Upper Cretaceous sediments from the Nelson Bore in Victoria. This assemblage of sporomorphs makes it clear that the upper sediments (grey shales and coal seams) of the supposedly Jurassic Walloon Series are actually Lower Cretaceous.

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Journal and Proceedings, Royal Society of New South Wales, Vol. 97, pp. 177–182, 1964

Minor Planets Observed at Sydney Observatory during 1963

W. H. Robertson
Sydney Observatory, Sydney

The following observations of minor planets were made photographically at Sydney Observatory with the 9-inch Taylor, Taylor and Hobson lens. Observations were confined to those with southern declinations in the *Ephemerides of Minor Planets* published by the Institute of Theoretical Astronomy at Leningrad.

On each plate two exposures, separated in declination by approximately 0′·5, were taken with an interval of about 20 minutes between them. The beginnings and endings of the exposures were automatically recorded on a chronograph by a contact on the shutter.

Rectangular coordinates of both images of the minor planet and three reference stars were measured in direct and reversed positions of the plate on a long screw measuring machine. The usual three star dependence reduction retaining second order terms in the differences of the equatorial coordinates was used. Proper motions, when they were available, were applied to bring the star positions to the epoch of the plate. Each exposure was reduced separately in order to provide a check by comparing the difference between the two positions with the motion derived from the ephemeris. The tabulated results are means of the two positions at the average time. No correction has been applied for aberration, light time or parallax but in Table I are given the factors which give the parallax correction when divided by the distance. The serial numbers follow on from those of a previous paper (Robertson, 1964). The observers named in Table II are W. H. Robertson (R), K. P. Sims (S) and H. W. Wood (W). The measurements were made by Mrs. J. Brannigan and Miss Y. Welch, who have also assisted in the computation.

Reference

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Table I

No.	Planet	U.T.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″
1531	16	1963	Apr.	18·64290	15	10	38·62	−13	27	55·4	+0·01	−3·0
1532	16	1963	May	14·64848	14	50	43·83	−11	51	26·5	+0·03	−3·3
1533	52	1963	Jul.	08·53582	17	31	41·79	−16	39	30·1	+0·06	−2·6
1534	58	1963	Jun.	18·68086	19	35	52·32	−14	56	46·1	+0·07	−2·9
1535	58	1963	Jul.	23·55228	19	06	50·22	−16	23	14·1	+0·03	−2·6
1536	64	1963	Jul.	08·56860	18	30	51·39	−24	14	48·6	+0·04	−1·5
1537	64	1963	Jul.	23·52145	18	18	11·06	−24	15	30·9	+0·04	−1·5
1538	70	1963	Jul.	30·64293	21	30	20·35	−37	24	01·0	+0·08	+0·5
1539	70	1963	Sep.	05·54574	20	59	03·88	−37	35	54·6	+0·18	+0·4
1540	84	1963	Jul.	31·62764	21	20	37·94	−21	35	54·7	+0·05	−1·9
1541	84	1963	Sep.	05·51426	20	47	39·10	−18	06	04·0	+0·07	−2·4
1542	86	1963	Jul.	31·59408	20	13	21·38	−24	18	26·9	+0·09	−1·5
1543	116	1963	Aug.	19·69748	23	51	50·98	−06	14	52·5	+0·10	−4·1
1544	116	1963	Sep.	10·62032	23	36	38·28	−08	01	12·9	+0·08	−3·8
1545	116	1963	Oct.	10·49042	23	14	15·54	−09	59	52·7	−0·02	−3·5
1546	129	1963	Oct.	23·70347	03	31	58·60	+01	47	49·0	+0·19	−5·1
1547	129	1963	Nov.	04·57418	03	23	13·74	+00	56	16·6	−0·08	−5·0
1548	133	1963	May	14·53447	14	27	52·52	−26	45	53·1	−0·02	−1·1
1549	148	1963	Nov.	12·53172	02	06	09·40	−27	56	55·7	+0·02	−0·9
1550	148	1963	Nov.	21·50861	02	01	25·74	−27	31	54·0	+0·03	−1·0
1551	152	1963	Jul.	31·66076	22	06	58·89	−29	56	26·8	+0·06	−0·6

Table I—*continued*

No.	Planet	U.T.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″
1552	152	1963	Sep.	11·54270	21	33	22·79	−31	35	52·7	+0·12	−0·4
1553	160	1963	Jun.	17·67790	18	55	43·09	−28	41	59·9	+0·16	−0·9
1554	160	1963	Jul.	09·58635	18	34	40·84	−29	08	24·9	+0·12	−0·8
1555	196	1963	Jul.	22·67049	21	30	04·32	−24	21	27·1	+0·09	−1·5
1556	196	1963	Jul.	29·65325	21	25	05·63	−24	58	11·0	+0·11	−1·4
1557	218	1963	Oct.	10·56205	00	27	42·77	−04	50	47·2	+0·04	−4·3
1558	218	1963	Oct.	16·53213	00	23	32·96	−05	39	35·7	+0·01	−4·2
1559	238	1963	Jul.	23·59400	20	19	31·37	−02	36	18·4	0·00	−4·5
1560	238	1963	Jul.	31·56080	20	13	18·83	−03	12	12·4	−0·02	−4·5
1561	248	1963	Jul.	04·62168	19	36	04·86	−16	54	43·6	+0·02	−2·6
1562	248	1963	Jul.	22·55216	19	18	47·55	−17	05	19·6	0·00	−2·5
1563	250	1963	Aug.	19·65679	23	04	37·48	−21	21	26·3	+0·07	−1·9
1564	250	1963	Sep.	10·59324	22	46	31·37	−22	23	02·1	+0·11	−1·8
1565	268	1963	May	23·57388	15	07	20·99	−13	53	51·4	+0·10	−3·0
1566	277	1963	Sep.	16·59269	23	12	39·30	−03	18	00·7	+0·09	−4·5
1567	294	1963	Sep.	17·63803	01	03	19·63	−01	47	02·2	+0·01	−4·7
1568	294	1963	Oct.	09·57832	00	48	18·00	−04	07	55·9	+0·04	−4·4
1569	317	1963	Apr.	18·64290	15	13	09·63	−15	03	11·1	0·00	−2·8
1570	317	1963	May	14·64848	14	48	44·81	−13	05	45·6	+0·03	−3·1
1571	326	1963	Jul.	09·67017	20	19	07·98	−66	44	39·3	+0·30	+4·6
1572	326	1963	Aug.	15·54394	19	26	02·47	−64	27	50·2	+0·36	+4·2
1573	350	1963	Oct.	09·61574	02	16	16·56	−24	55	56·2	−0·03	−1·4
1574	350	1963	Nov.	04·53857	01	52	56·42	−24	50	09·7	0·00	−1·4
1575	357	1963	Oct.	10·59931	01	02	17·14	−13	26	55·4	+0·08	−3·1
1576	357	1963	Oct.	24·54807	00	53	00·50	−14	36	26·8	+0·06	−2·9
1577	364	1963	May	20·55123	15	28	19·91	−11	00	02·5	−0·05	−3·4
1578	368	1963	May	23·61303	16	38	02·83	−17	57	45·4	+0·02	−2·4
1579	369	1963	Oct.	17·65963	03	08	01·41	−00	58	13·8	+0·06	−4·8
1580	369	1963	Oct.	24·61795	03	02	20·73	−01	17	10·7	0·00	−4·7
1581	369	1963	Nov.	19·57927	02	38	02·12	−01	16	36·1	+0·09	−4·7
1582	388	1963	Jun.	17·59740	17	20	47·24	−32	02	48·8	+0·11	−0·3
1583	388	1963	Jul.	08·50368	17	03	10·45	−32	22	39·7	+0·02	−0·2
1584	412	1963	Oct.	16·60276	01	47	30·71	−11	11	19·0	+0·05	−3·4
1585	412	1963	Oct.	23·58050	01	41	36·18	−11	36	05·7	+0·05	−3·3
1586	412	1963	Nov.	18·54625	01	23	07·46	−11	33	35·6	+0·20	−3·4
1587	438	1963	Sep.	17·63803	01	08	06·57	−01	13	29·6	0·00	−4·7
1588	438	1963	Oct.	09·57832	00	48	33·72	−02	33	34·5	+0·04	−4·6
1589	446	1963	May	15·61578	15	31	42·85	−23	05	34·4	+0·11	−1·7
1590	446	1963	Jun.	14·46157	15	04	54·28	−23	06	48·3	−0·06	−1·6
1591	451	1963	Oct.	17·65963	03	08	18·42	−01	13	56·7	+0·06	−4·7
1592	451	1963	Oct.	24·61795	03	03	10·00	−01	30	11·5	0·00	−4·7
1593	451	1963	Nov.	19·57927	02	41	01·96	−01	33	31·5	+0·08	−4·7
1594	462	1963	Aug.	19·69748	23	41	59·69	−06	31	22·7	+0·12	−4·1
1595	462	1963	Aug.	26·64883	23	38	06·24	−07	07	14·4	+0·04	−3·9
1596	462	1963	Sep.	10·62032	23	27	26·17	−08	31	47·3	+0·10	−3·8
1597	478	1963	Jul.	23·59400	20	17	00·78	−01	24	26·6	+0·01	−4·7
1598	478	1963	Jul.	31·56080	20	10	46·82	−01	36	45·9	−0·01	−4·7
1599	481	1963	Jul.	18·58955	19	40	48·41	−32	28	39·3	+0·04	−0·2
1600	481	1963	Jul.	30·57396	19	29	02·75	−33	09	00·6	+0·13	−0·2
1601	487	1963	Jul.	04·62168	19	42	23·71	−19	47	20·8	+0·01	−2·1
1602	487	1963	Jul.	31·53078	19	18	22·72	−22	20	15·7	+0·01	−1·7
1603	494	1963	Jul.	11·68401	21	22	30·36	−26	28	47·8	+0·05	−1·1
1604	494	1963	Aug.	27·53564	20	45	12·37	−28	49	15·0	+0·07	−0·8
1605	518	1963	May	22·66497	18	00	39·12	−14	04	34·9	0·00	−3·0
1606	518	1963	Jun.	18·58269	17	40	36·53	−12	07	18·3	+0·02	−3·2
1607	519	1963	Jul.	25·61683	20	37	20·34	−37	42	13·4	+0·07	+0·6
1608	519	1963	Jul.	29·61440	20	33	22·04	−38	00	05·5	+0·11	+0·6
1609	519	1963	Aug.	19·54369	20	14	10·61	−38	26	33·8	+0·11	+0·6
1610	530	1963	Jul.	04·62168	19	40	43·24	−16	43	17·7	+0·01	−2·6
1611	530	1963	Jul.	22·55216	19	26	55·03	−18	12	59·6	−0·02	−2·4
1612	535	1963	Oct.	16·56476	01	12	13·73	−03	07	36·6	0·00	−4·5
1613	535	1963	Nov.	07·54953	00	55	03·17	−03	51	31·4	+0·18	−4·4
1614	540	1963	May	22·58608	15	56	44·91	−13	39	04·7	+0·02	−3·0
1615	540	1963	Jun.	18·49209	15	34	59·56	−11	51	00·5	0·00	−3·3
1616	578	1963	May	22·55770	15	15	05·10	−22	56	35·1	+0·02	−1·6

TABLE I—*continued*

No.	Planet	U.T.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″
1617	578	1963	Jun.	14·46157	14	57	14·60	−22	32	46·9	−0·05	−1·7
1618	596	1963	Oct.	10·59931	01	04	36·39	−12	57	44·5	+0·08	−3·1
1619	596	1963	Oct.	24·54807	00	53	10·85	−13	11	03·2	+0·06	−3·1
1620	600	1963	Aug.	27·62460	22	40	11·65	−13	20	21·8	+0·10	−3·1
1621	600	1963	Sep.	18·54856	22	23	53·92	−16	09	10·1	+0·08	−2·7
1622	602	1963	Jul.	25·65576	22	03	18·77	−19	03	33·8	−0·01	−2·2
1623	602	1963	Aug.	26·54363	21	33	04·81	−18	05	38·1	−0·02	−2·4
1624	618	1963	Oct.	17·63038	02	09	59·09	−13	54	03·1	+0·09	−3·0
1625	618	1963	Oct.	24·58948	02	04	36·00	−14	17	10·3	+0·04	−2·9
1626	618	1963	Nov.	18·58046	01	47	06·67	−14	05	58·9	+0·25	−3·2
1627	636	1963	May	15·61578	15	38	00·91	−24	03	39·8	+0·10	−1·5
1628	660	1963	Nov.	18·64941	05	10	11·97	+00	01	18·7	+0·04	−4·9
1629	660	1963	Dec.	11·52454	04	49	32·26	−00	47	58·1	−0·11	−4·8
1630	660	1963	Dec.	19·55658	04	42	15·15	−00	39	24·8	+0·07	−4·8
1631	683	1963	May	22·52936	14	26	10·68	−29	38	40·4	+0·04	−0·6
1632	686	1963	Jun.	19·66513	18	48	12·60	−06	58	27·8	+0·13	−4·0
1633	686	1963	Jul.	22·52001	18	18	52·49	−02	31	47·2	+0·03	−4·6
1634	715	1963	Oct.	17·59361	01	03	36·34	−05	20	19·7	+0·12	−4·2
1635	718	1963	May	14·67934	17	09	20·30	−28	30	13·8	+0·10	−0·8
1636	747	1963	Nov.	04·60744	04	02	29·30	−14	27	17·3	−0·07	−2·9
1637	747	1963	Nov.	12·59467	03	57	15·88	−14	46	04·6	−0·03	−2·9
1638	747	1963	Nov.	18·61226	03	52	45·56	−14	41	13·8	+0·09	−2·9
1639	753	1963	Jun.	19·69724	19	29	50·04	−34	47	54·3	+0·17	0·0
1640	753	1963	Jul.	09·62567	19	12	43·96	−38	11	01·9	+0·16	+0·5
1641	772	1963	Jul.	30·69203	22	21	18·60	−52	40	03·2	+1·07	+2·7
1642	772	1963	Aug.	19·61329	21	59	57·88	−54	43	09·0	+0·13	+3·1
1643	772	1963	Sep.	10·53991	21	36	43·12	−54	31	11·2	+0·15	+3·0
1644	779	1963	Apr.	17·55126	13	01	47·46	−29	59	42·7	−0·01	−0·6
1645	808	1963	Apr.	18·64290	15	09	02·26	−12	58	30·4	+0·01	−3·1
1646	868	1963	Aug.	15·66845	22	56	03·43	−13	03	48·5	+0·10	−3·1
1647	868	1963	Aug.	27·62460	22	47	29·34	−14	30	34·3	+0·08	−2·9
1648	868	1963	Sep.	09·58379	22	37	02·50	−15	58	31·0	+0·09	−2·7
1649	898	1963	Jul.	02·58464	18	29	24·83	−08	44	37·4	+0·03	−3·7
1650	898	1963	Jul.	18·51162	18	21	03·97	−06	46	15·4	−0·04	−4·0
1651	909	1963	Oct.	16·60276	01	52	03·15	−12	13	48·7	+0·04	−3·2
1652	909	1963	Oct.	23·58050	01	47	31·21	−12	55	09·0	+0·04	−3·1
1653	909	1963	Nov.	18·54625	01	32	59·92	−13	59	35·7	+0·18	−3·1
1654	940	1963	Aug.	27·57726	21	48	13·71	−23	05	33·0	+0·06	−1·7
1655	940	1963	Sep.	16·54469	21	36	05·99	−23	42	14·9	+0·16	−1·7
1656	976	1963	Jun.	27·63298	18	59	24·09	−16	13	51·1	+0·08	−2·7
1657	1021	1963	Nov.	18·64941	05	26	35·81	+01	19	49·3	0·00	−5·0
1658	1021	1963	Dec.	20·50295	04	57	54·78	+05	06	24·4	−0·12	−5·5
1659	1048	1963	Jul.	11·60722	19	53	53·52	−44	17	07·3	0·00	+1·6
1660	1048	1963	Jul.	15·62022	19	49	23·26	−44	41	24·5	+0·12	+1·6
1661	1048	1963	Jul.	30·53813	19	33	05·67	−45	27	38·7	−0·01	+1·8
1662	1089	1963	Sep.	18·63356	00	18	49·55	−05	27	33·7	+0·10	−4·2
1663	1089	1963	Oct.	09·53932	23	58	47·12	−07	10	53·8	+0·03	−3·9
1664	1248	1963	Jul.	16·64494	21	06	52·05	−27	09	14·0	0·00	−1·0
1665	1278	1963	Jul.	11·65079	20	49	56·31	−28	48	49·8	+0·02	−0·8
1666	1278	1963	Jul.	22·63298	20	44	19·42	−31	26	12·7	+0·07	−0·4
1667	1278	1963	Jul.	30·60879	20	38	40·79	−33	11	45·5	+0·08	−0·1
1668	1407	1963	Jul.	22·59520	20	10	15·72	−14	47	05·1	+0·02	−2·9
1669	1418	1963	May	22·62208	16	37	09·13	−35	41	06·6	+0·05	+0·3
1670	1418	1963	Jun.	19·56017	16	04	26·53	−35	15	19·8	+0·19	0·0
1671	1467	1963	Jul.	22·67049	21	30	03·37	−25	21	08·1	+0·09	−1·4
1672	1467	1963	Jul.	29·65325	21	23	25·50	−25	07	21·7	+0·11	−1·4
1673	1514	1963	Aug.	15·63275	21	57	53·89	−12	10	01·3	+0·11	−3·3
1674	1580	1963	May	20·69226	18	12	28·46	−34	59	00·3	+0·05	+0·2
1675	1580	1963	May	23·66113	17	44	22·16	−50	35	51·9	+0·05	+2·5
1676	1606	1963	Jun.	19·61573	17	37	22·78	−09	26	53·0	+0·13	−3·7

TABLE II

No.	Comparison Stars	Dependences			
1531	Yale *11* 5299, 5334, 5335	0·40001	0·33110	0·26889	R
1532	Yale *11* 5211, 5215, 5226	0·37569	0·37106	0·25325	R
1533	Yale *12* I 6293, 6300, 6328	0·34678	0·40181	0·25141	W
1534	Yale *12* I 7359, 7374, 7390	0·29112	0·47266	0·23623	W
1535	Yale *12* I 7093, 7108, 7116	0·25172	0·37211	0·37617	S
1536	Yale *14* 12847, 12865, 12905	0·28169	0·36162	0·35669	W
1537	Yale *14* 12669, 12708, 12723	0·18319	0·54816	0·26865	S
1538	Cape *18* 11082, 11094, 11108	0·33768	0·43049	0·23183	W
1539	Cape *18* 10847, 10866, 10893	0·32755	0·36256	0·30990	S
1540	Yale *13* I 9145, 9170, *14* 14747	0·33754	0·36852	0·29394	W
1541	Yale *12* II 8916, 8937, 8944	0·15257	0·45781	0·38963	S
1542	Yale *14* 14062, 14070, 14092	0·42335	0·28355	0·29310	W
1543	Yale *16* 8420, 8427, 8428	−0·03102	0·78348	0·24754	W
1544	Yale *16* 8350, 8364, 8368	0·12684	0·54986	0·32330	W
1545	Yale *11* 8149, 8150, 8165	0·19146	0·62712	0·18142	W
1546	Yale *20* 1018, 1026, 1037	0·33953	0·41206	0·24842	W
1547	Yale *21* 729, 741, 744	0·38201	0·45631	0·16168	R
1548	Yale *14* 10440, 10462, 10488	0·32552	0·30386	0·37062	R
1549	Yale *13* II 800, 814, 819	0·41880	0·23698	0·34422	S
1550	Yale *13* II 748, 770, 800	0·27678	0·46370	0·25953	W
1551	Cape *17* 12024, 12059, Yale *13* II 14407	0·24808	0·37151	0·38041	W
1552	Cape *17* 11747, 11779, 11786	0·38416	0·34447	0·27137	W
1553	Yale *13* II 12379, 12391, 12404	0·46542	0·22236	0·31222	W
1554	Yale *13* II 12072, 12090, 12112	0·13223	0·57883	0·28894	W
1555	Yale *14* 14804, 14808, 14838	0·22437	0·45262	0·32302	S
1556	Yale *14* 14770, 14774, 14798	0·53176	0·29128	0·17696	W
1557	Yale *17* 99, 102, 112	0·46337	0·14133	0·39530	R
1558	Yale *16* 71, 87, *17* 83	0·36334	0·38075	0·25591	S
1559	Yale *17* 7018, 7021, 7036	0·08896	0·43856	0·47248	S
1560	Yale *17* 6957, 6975, 6986	0·23634	0·30032	0·46334	W
1561	Yale *12* I 7363, 7366, 7392	0·17517	0·31156	0·51327	S
1562	Yale *12* I 7217, 7236, 7253	0·36495	0·38680	0·24826	S
1563	Yale *13* I 9707, 9723, *14* 15547	0·28538	0·35183	0·36279	W
1564	Yale *14* 15377, 15390, 15406	0·40346	0·25033	0·34622	W
1565	Yale *11* 5288, 5299, 5317	0·19462	0·42212	0·38326	S
1566	Yale *17* 7993, 8010, 8020	0·36769	0·18014	0·45217	R
1567	Yale *17* 234, 248, *21* 214	0·39607	0·36057	0·24336	R
1568	Yale *17* 177, 179, 187	0·32015	0·11286	0·56699	R
1569	Yale *12* I 5611, 5612, 5623	0·48277	0·25136	0·26586	R
1570	Yale *11* 5197, 5208, 5216	0·28002	0·35862	0·36135	R
1571	LP1 D 4024, 4034, 4044	0·27474	0·48957	0·23569	W
1571	Cape *20* 5844, 5910 LP1 C 3896	0·20236	0·33792	0·45973	S
1573	Yale *14* 1047, 1068, 1072	0·39267	0·29122	0·31611	R
1574	Yale *14* 878, 880, 900	0·54888	0·15328	0·29784	R
1575	Yale *11* 206, 216, *12* II 270	0·33481	0·26938	0·39581	R
1576	Yale *12* I 215, 232, 236	0·31156	0·38858	0·29986	W
1577	Yale *11* 5407, 5432, *16* 5413	0·42428	0·33705	0·23867	S
1578	Yale *12* II 6812, *12* I 5995, 6009	0·40889	0·30200	0·28911	S
1579	Yale *21* 660, 675, 678	0·27157	0·31265	0·41579	S
1580	Yale *21* 643, 656 *17* 743	0·33360	0·40802	0·25838	W
1581	Yale *21* 540, 546, 550	0·18776	0·31886	0·49338	W
1582	Cape *17* 9166, 9201, 9210	0·47675	0·33005	0·19321	W
1583	Cape *17* 8963, 8982, 9007	0·24689	0·26840	0·48471	W
1584	Yale *11* 399, 413, 428	0·51769	0·31540	0·16691	S
1585	Yale *11* 378, 389, 394	0·38024	0·32901	0·29075	W
1586	Yale *11* 294, 302, 307	0·23089	0·44425	0·32486	W
1587	Yale *21* 214, 223, 225	0·16884	0·51965	0·31151	R
1588	Yale *17* 169, 191, 192	0·33430	0·33522	0·33049	R
1589	Yale *14* 11023, 11031, 11040	0·33178	0·23625	0·43197	R
1590	Yale *14* 10787, 10801, 10816	0·14315	0·32694	0·52991	R
1591	Yale *21* 660, 675, 678	0·19637	0·57864	0·22500	S
1592	Yale *21* 643, 656, *17* 743	0·17867	0·30936	0·51197	W
1593	Yale *17* 651, 667 *21* 560	0·29965	0·32209	0·37826	W
1594	Yale *16* 8381, 8388, 8395	0·32858	0·49586	0·17555	W
1595	Yale *16* 8350, 8362, 8376	0·10911	0·29205	0·59884	R
1596	Yale *16* 8322, 8328, 8338	0·34781	0·27825	0·37394	W
1597	Yale *21* 5114, 5134, 5139	0·26064	0·26499	0·47438	S

TABLE II—*continued*

No.	Comparison Stars	Dependences			
1598	Yale *21* 5077, 5094, 5099	0·14008	0·38665	0·47326	W
1599	Cape *17* 10718, 10759, 10765	0·22906	0·28416	0·48679	R
1600	Cape *17* 10632, 10642, 10660	0·35928	0·51486	0·12585	W
1601	Yale *12* II 8450, 8481, *13* I 8457	0·18228	0·35789	0·45983	S
1602	Yale *14* 13437, 13481, 13485	0·29574	0·32346	0·38080	W
1603	Yale *14* 14731, 14772, *13* II 14065	0·28346	0·27564	0·44090	W
1604	Yale *13* II 13671, 13676, 13718	0·28946	0·29339	0·41716	R
1605	Yale *11* 6136, *12* I 6495, 6518	0·31318	0·30804	0·37878	S
1606	Yale *11* 6049, 6056, 6066	0·27552	0·52141	0·20306	W
1607	Cape *18* 10680, 10713, 10715	0·25718	0·33882	0·40400	S
1608	Cape *17* 10668, 10676, 10697	0·46641	0·26656	0·26702	W
1609	Cape *18* 10494, 10527, 10529	0·24223	0·22136	0·53641	W
1610	Yale *12* I 7398, 7426, 7433	0·43423	0·36254	0·20323	S
1611	Yale *12* II 8311, 8347, 8358	0·27218	0·37517	0·35265	S
1612	Yale *17* 276, 280, 289	0·44519	0·20413	0·35067	S
1613	Yale *17* 196, 206, 228	0·40001	0·36843	0·23155	R
1614	Yale *11* 5530, 5545, 5546	0·28878	0·53781	0·17340	S
1615	Yale *11* 5441, 5443, 5461	0·25211	0·26964	0·47825	W
1616	Yale *14* 10879, 10891, 10913	0·29751	0·49760	0·20489	S
1617	Yale *14* 10726, 10748 *13* I 6222	0·33502	0·27857	0·38640	R
1618	Yale *11* 216, 228, 236	0·47965	0·31638	0·20397	R
1619	Yale *11* 173, 183, 188	0·34197	0·19630	0·46173	W
1620	Yale *11* 7983, 8010 *12* I 8446	0·23610	0·46616	0·29774	R
1621	Yale *12* I 8358, 8372, 8384	0·24741	0·28146	0·47113	R
1622	Yale *12* II 9401, 9413, 9415	0·62780	0·22863	0·14358	S
1623	Yale *12* II 9226, 9256, 9257	0·51742	0·19998	0·28260	R
1624	Yale *11* 495, *12* I 571, 576	0·16337	0·31347	0·52316	S
1625	Yale *12* I 535, 549, 564	0·36063	0·38606	0·25331	W
1626	Yale *12* I 443, 445, 473	0·30068	0·30575	0·39357	W
1627	Yale *14* 11061, 11084, 11102	0·23797	0·37292	0·38910	R
1628	Yale *21* 1225, 1240, 1247	0·32680	0·43127	0·24193	W
1629	Yale *21* 1095, 1123, 1125	0·45704	0·33339	0·20956	R
1630	Yale *21* 1067, 1069, 1075	0·46816	0·23977	0·29208	W
1631	Yale *13* II 9130, 9139, 9156	0·42531	0·24377	0·33092	S
1632	Yale *16* 6371, 6379, 6404	0·35620	0·30670	0·33710	W
1633	Yale *17* 6131, 6136, 6155	0·26639	0·40839	0·32522	S
1634	Yale *16* 213, *17* 242, 260	0·41468	0·26299	0·32233	S
1635	Yale *13* II 10850, 10874, 10881	0·31846	0·19220	0·48933	R
1636	Yale *12* I 1069, 1081, 1088	0·13660	0·31370	0·54969	R
1637	Yale *12* I 1045, 1056, 1082	0·22182	0·52708	0·25110	S
1638	Yale *12* I 1024, 1031, 1045	0·07787	0·59618	0·32595	W
1639	Cape *18* 10110, *17* 10648, 10686	0·30063	0·48261	0·21676	W
1640	Cape *18* 9970, 9982, 10008	0·29427	0·25939	0·44634	W
1641	Cape *19* 8716, 8717, 8727	0·41056	0·23991	0·34953	W
1642	Cape *19* 8572, 8614, 8632	0·53728	0·30986	0·15287	W
1643	Cape *19* 8420, 8430, 8470	0·36910	0·33767	0·29323	W
1644	Yale *13* II 8329, 8337, 8358	0·35268	0·26522	0·38209	R
1645	Yale *11* 5299, 5320, 5335	0·55296	0·20671	0·24033	R
1646	Yale *11* 8063, 8066, 8075	0·38965	0·32155	0·28880	S
1647	Yale *12* I 8458, 8472, 8485	0·21698	0·24637	0·53664	R
1648	Yale *12* I 8422, 8427, 8439	0·30132	0·23033	0·46835	W
1649	Yale *16* 6204, 6210, 6220	0·16034	0·53368	0·30598	S
1650	Yale *16* 6157, 6172, 6190	0·38647	0·25380	0·35973	R
1651	Yale *11* 424, 428, 436	0·29577	0·36926	0·33497	S
1652	Yale *11* 400, 408, 423	0·37993	0·28617	0·33390	W
1653	Yale *12* I 380, 401, *11* 344	0·23682	0·47115	0·29203	W
1654	Yale *14* 14922, 14952, 14977	0·39726	0·13071	0·47203	R
1655	Yale *14* 14855, 14862, 14878	0·27764	0·45316	0·26920	R
1656	Yale *12* I 7020, 7045, 7057	0·31955	0·31557	0·36488	R
1657	Yale *20* 1743, 1754, 1773	0·29448	0·47337	0·23215	W
1658	Yale *20* 1500, 1550 *22* 1923	0·30255	0·31301	0·38444	S
1659	Cape Ft. 18889 Cape Z. 18502, 18511	0·17748	0·59130	0·23122	W
1660	Cord. D 14477, 14496, 14529	0·11320	0·44595	0·44086	R
1661	Cord. D 14327, 14360, 14394	0·25019	0·31670	0·43310	W
1662	Yale *17* 60, 74 *16* 69	0·40621	0·26474	0·32905	R
1663	Yale *16* 8442, 8449, 8461	0·15473	0·44300	0·40227	R
1664	Yale *13* II 13903, 13922, 13945	0·37140	0·39249	0·23612	R

TABLE II—*continued*

No.	Comparison Stars	Dependences			
1665	Yale *13* II 13728, 13741, 13765	0·15823	0·58039	0·26138	W
1666	Cape *17* 11332, 11337, 11369	0·40773	0·36344	0·22884	S
1667	Cape *17* 11265, 11301, 11315	0·28175	0·37144	0·34681	W
1668	Yale *12* I 7570, 7584, 7609	0·27535	0·30342	0·42123	S
1669	Cape *18* 8223, 8235, 8257	0·40395	0·06982	0·52623	S
1670	Cape *18* 7975, 8011, *17* 8391	0·39186	0·28734	0·32080	W
1671	Yale *14* 14799, 14818, 14830	0·31873	0·16557	0·51570	S
1672	Yale *14* 14745, 14770, 14774	0·39302	0·32255	0·28444	W
1673	Yale *11* 7779, 7797, 7804	0·34498	0·31827	0·33676	S
1674	Cape *17* 9777, 9829, *18* 9363	0·44339	0·26027	0·29633	S
1675	Cape Ft. 17253, 17280, 17391	0·18512	0·43616	0·37872	S
1676	Yale *16* 5956, 5968, 5974	0·29850	0·18298	0·51852	W

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Occultations Observed at Sydney Observatory during 1962-63

K. P. Sims

The following observations of occultations were made at Sydney Observatory with the 11½-inch telescope. A tapping key was used to record the times on a chronograph. The reduction elements were computed by the method given in the occultation Supplement to the *Nautical Almanac* for 1938 and the reduction completed by the method given there. For 1962 a correction of $+0 \cdot 00944$ hour (=34 seconds) was applied to the observed time to convert it to Ephemeris Time with which *The Astronomical Ephemeris for 1962* was entered to obtain the position and parallax of the Moon. For 1963 a correction of $+0 \cdot 00972$ hour (=35 seconds) was applied to the observed time to convert it to Ephemeris Time with which *The Astronomical Ephemeris for 1963* was entered to obtain the position and parallax of the Moon. The apparent places of the stars of the 1962–63 occultations were provided by H.M. Nautical Almanac Office.

Table I gives the observational material. The serial numbers follow on from those of the previous report (Sims, 1963). The observers were W. H. Robertson (R), K. P. Sims (S), and H. W. Wood (W). In all cases the phase observed was disappearance at the dark limb. Table II gives the results of the reductions which were carried out in duplicate. The Z.C. numbers given are those of the *Catalog of 3539 Zodiacal Stars for the Equinox* 1950·0 (Robertson, 1940).

References

Robertson, A. J., 1940. Astronomical Papers of the American Ephemeris, Vol. X, Part II.

Sims, K. P., 1963. *J. Proc. Roy. Soc. N.S.W.*, **96**, 37 ; *Sydney Observatory Papers*, **44**.

Table I

Serial No.	Z.C. No.	Mag.	Date	U.T.	Observer
425	1362	7·4	1962 Jun. 7	9 39 27·2	W
426	2279	6·2	1962 Jul. 13	9 57 59·0	S
427	2240	6·8	1962 Aug. 9	12 58 59·0	R
428	2760	6·7	1962 Sep. 9	12 41 33·1	W
429	2908	6·9	1962 Sep. 10	11 23 47·0	S
430	2994	6·1	1962 Oct. 8	10 28 02·4	R
431	3091	6·9	1962 Nov. 5	11 14 14·6	R
432	3245	6·9	1962 Nov. 6	12 26 57·5	S
433	847	3·0	1963 Feb. 4	9 40 44·5	R
434	1021	6·3	1963 Feb. 5	11 37 11·6	W
435	1295	6·5	1963 Apr. 30	10 34 49·1	R
436	1296	6·5	1963 Apr. 30	10 42 34·0	R
437	2184	7·0	1963 Jul. 2	12 00 44·2	S
438	2436	6·3	1963 Jul. 4	13 30 14·3	S
439	2133	5·6	1963 Jul. 29	9 07 16·5	S
440	2245	6·4	1963 Jul. 30	8 38 56·8	R
441	3171	3·8	1963 Sep. 2	8 43 17·8	R
442	3190	3·0	1963 Sep. 2	13 01 28·9	S
443	2291	5·5	1963 Sep. 23	10 42 34·2	R
444	2838	5·6	1963 Sep. 27	10 11 09·8	R
445	2964	6·6	1963 Sep. 28	8 41 45·8	W
446	3113	5·4	1963 Sep. 29	10 09 58·7	W
447	2785	6·8	1963 Oct. 24	9 35 43·1	W
448	3069	6·2	1963 Oct. 26	12 18 09·5	W

TABLE II

Serial No.	Luna-tion	p	q	p^2	pq	q^2	$\Delta\sigma$	$p\Delta\sigma$	$q\Delta\sigma$	Coefficient of $\Delta\alpha$	Coefficient of $\Delta\delta$
425	488	+55	+84	30	+46	70	−1·8	−1·0	−1·5	+10·1	+0·71
426	489	+44	+90	19	+40	81	−1·7	−0·7	−1·5	+ 9·3	+0·76
427	490	+51	+86	26	+44	74	−1·9	−1·0	−1·6	+10·3	+0·70
428	491	+65	−76	42	−49	58	−0·1	−0·1	+0·1	+ 9·4	−0·75
429	491	+84	+55	70	+46	30	+0·2	+0·2	+0·1	+11·0	+0·63
430	492	+98	−20	96	−20	4	−3·8	−3·7	+0·8	+14·1	−0·05
431	493	+31	+95	10	+29	90	−0·9	−0·3	−0·9	+ 1·4	+0·99
432	493	+86	−52	73	−44	27	+0·8	+0·7	−0·4	+14·1	−0·26
433	496	+92	+39	85	+36	15	−1·3	−1·2	−0·5	+12·1	+0·50
434	496	+100	+ 1	100	+ 1	0	−1·7	−1·7	0·0	+13·9	+0·04
435	499	+73	−68	53	−50	47	+0·3	+0·2	−0·2	+ 8·5	−0·80
436	499	+64	−77	41	−49	59	+0·3	+0·2	−0·2	+ 7·0	−0·87
437	501	+85	+53	72	+45	28	−1·9	−1·6	−1·0	+14·1	+0·25
438	501	+71	−70	51	−50	49	−1·3	−0·9	+0·9	+ 8·0	−0·82
439	502	+92	+39	85	+36	15	−0·9	−0·8	−0·4	+14·6	+0·07
440	502	+100	+ 8	99	+ 8	1	−0·6	−0·6	0·0	+14·2	−0·20
441	503	+97	−23	95	−22	5	−4·0	−3·9	+0·9	+14·3	+0·02
442	503	+99	−17	97	−17	3	−2·8	−2·8	+0·5	+14·3	+0·09
443	504	+89	+45	80	+40	20	−1·8	−1·6	−0·8	+14·1	+0·20
444	504	+77	+64	59	+49	41	−1·7	−1·3	−1·1	+10·2	+0·68
445	504	+38	−93	14	−35	86	−0·9	−0·3	+0·8	+ 7·0	−0·87
446	504	+98	+18	97	+18	3	−1·0	−1·0	−0·2	+13·1	+0·40
447	505	+83	−56	69	−46	31	−0·2	−0·2	+0·1	+11·8	−0·53
448	505	+99	−13	98	−13	2	−1·4	−1·4	+0·2	+14·1	+0·08

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James Dwight Dana in New South Wales, 1839-1840

ANN MOZLEY

Basser Library, Australian Academy of Science, and Dept. of History, Research School of Social Sciences, Australian National University, Canberra

> " A sandstone bluff, from one hundred and fifty to two hundred feet in height, forms the North and South Heads of Port Jackson. The rock lies in nearly horizontal beds, brought out in bold relief by the partial removal of occasional softer beds, or by natural excavations along the junction of the several layers. Passing the narrow entrance between the capes, the same light gray or grayish-yellow sandstone is seen bordering the bay throughout its extent, stretching far away around its deep sinuous coves, and advancing into prominent headlands that often confine the view to a small portion of this large expanse of waters. The sandstone usually presents a low bluff front to the bay : the upper layers retreat either by terraces or a gradual slope, into rounded elevations covered with a sparse growth of shrubbery or forest trees. These slopes continue in many places to the water's edge, especially at the head of the coves, where they terminate below in a broad sand-beach, or a small marsh, more or less changed to meadow-land by washings from the adjoining declivities." (Dana, 1849, p. 449.)

In these terms, James Dwight Dana described Sydney Harbour, which he entered aboard the U.S. man-of-war *Peacock* on 29 November 1839. Dana was then twenty-six, and destined within the decade to succeed Benjamin Silliman as Professor of Natural History at Yale and to become for the next half century the dominating figure of American geological science.

Dana had already demonstrated his great ability as a mineralogist before he arrived in Australia in 1839. He had studied geology and mineralogy under Silliman at Yale, but the opportunity of foreign travel prompted him to abandon his studies before graduation in 1833 and to take the post of mathematical instructor on the Mediterranean cruise of S.S. *Delaware*. It was not, however, mathematics but geology that stimulated his perceptive mind, and Dana's description of a visit to Vesuvius posted to Silliman from abroad, won him a personal assistantship to the Professor on his return in 1836. Two years later he published *A System of Mineralogy*, widely regarded as his most original work, and a classic of mineralogy.

It was Asa Gray, Professor of Botany at Harvard, who persuaded Dana to join the United States Exploring Expedition as geologist and mineralogist in 1838. Commissioned under Captain Charles Wilkes, the Expedition was the first hydrographic and scientific survey to be undertaken by the United States Government in the international sphere, and had as its object the exploration and survey of the Antarctic coastline, the Pacific Islands and the north-west American coast, and the preparation of scientific reports. Its carefully selected corps of civilian scientists included, in addition to Dana, two men of considerable reputation in their fields, Horatio Hale, the philologist, and Dr. Charles Pickering, chief zoologist to the Expedition and a former Curator of the Academy of Natural Sciences.

The six vessels sailed from Norfolk, Virginia, in August 1838, and after a sixteen months' cruise of South American waters and the Pacific, the flagship *Vincennes* and the sloop-of-war *Peacock* carrying the scientific contingent arrived off Port Jackson on 29 November 1839 at 8 p.m. Their arrival was unexpected, and no pilot met them at the entrance of Sydney Heads, but Wilkes was anxious to avoid loss of time and to catch the favourable wind. Thus on a dark night, unknown to the harbour authorities and relying on their own charts to negotiate the channel, the two ships stole silently into harbour and at 10.30 p.m. " quietly dropped anchor off the Cove, in the midst of the shipping, without anyone having the least idea of our arrival " (Wilkes, 1852, p. 208).

When the people of Sydney looked abroad the following morning, they were astonished to see two men-of-war anchored among their shipping directly below the Fort. " What a scrape should we have been in ", exclaimed one citizen in his diary, " had there been war " (Clarke, Diary, entry 4 Dec. 1839).

Despite their unorthodox arrival, the residents greeted the Squadron with hospitality and enthusiasm. There was much in the Colony that reminded the visitors of home: "The acquisition of wealth", Captain Wilkes noted, "seems the only object of exertion here, and speculation was as rife as we had left it in the United States" (Wilkes, 1852, p. 211). The officers observed the arrival of a convict ship and were struck by the healthy aspect of the disembarking passengers. "They were treated in all respects", Wilkes recorded in some wonder, "as if they were free" (p. 277).

Dana did not remain long in the town and the day after their arrival accepted the invitation with Dr. Charles Pickering, to visit the estate of W. Stephens at Puenbuen, some 120 miles from Newcastle near the source of the Hunter River (Pickering, 1850). The two scientists travelled by steamer to Newcastle and thence overland up the Hunter Valley through Maitland, Patrick Plains and Muswellbrook to Stephens' station, and it was here that Dana began his careful examination of the Australian landscape and, in his own words, sought "to gratify but partially, in a geological point of view the curiosity which so strange a land may well excite" (Dana, 1849, p. 458).

To the small coterie of scholars and scientific amateurs in the Colony, cut off from the currents of discovery and research, the advent of the civilian corps of the United States Exploring Expedition offered the stimulating opportunity for discussion and scientific exchange. "I wish I could meet with Mr. Dana", the Rev. W. B. Clarke wrote in his diary on December 16th. Next morning, the Expedition's Chaplain introduced him to the geologist, back that day from the country, on board the *Peacock*.

William Branwhite Clarke was a graduate of Cambridge, where he had studied geology under Professor Adam Sedgwick, and was already known in geological circles in London when poverty and long delay in Church preferment drove him to accept a parish in New South Wales. He had arrived in the Colony in May 1839 with the eager recommendations of his colleagues of the Geological Society of London to turn his particular attention to the coal deposits of Australia and to investigate the stratigraphy of this little known land. With the exception of Charles Darwin, who called briefly aboard the *Beagle* in 1836, Clarke was the first university trained geologist to reach Australia, where his pioneering work over vast tracts of New South Wales was to earn him the title of the "Father of Australian Geology" and a Fellowship of the Royal Society towards the close of a long and energetic life.

His meeting with Dana who, while fifteen years his junior, had already demonstrated the quality and originality of his mind, gave an exhilarating start to Clarke's geological researches in the Colony and was the beginning of a long friendship maintained by correspondence until the end of the clergyman's life. It is indeed Clarke's diary, which he kept faithfully during his first two years in Australia and into which he poured his graphic impressions of Colonial life, that provides the main source of information of Dana's now forgotten visit to New South Wales.

Three days after their first meeting Dana and Clarke were together again at the elaborate luncheon given by the United States Squadron on the lawns at Fort Macquarie, where, under marquees decked with flags and evergreens, they met another scientific visitor, the Polish Count Strzelecki, who arriving in the Colony in April 1839 with the avowed intention of conducting a mineralogical survey of New South Wales, had just returned from an excursion across the Blue Mountains to Bathurst and told Clarke and Dana that he had found "the geology of that country very tame" (Clarke, Diary, 20 Dec. 1839). It was a verdict the clergyman was to remember with interest when Strzelecki asserted his claim to have discovered gold in the region, as the rushes of 1851 precipitated a lively scramble for priorities in the early discovery of Australian gold. Clarke's own interest was more than academic; he too had found traces of gold in the mountains in 1841.

It was also in Clarke's company that Dana visited the house of Mr. (later Sir Charles) Nicholson where, Clarke enthusiastically reported, "Dana and I went all over the geology of America and Europe" (Diary, 23 Dec. 1839). From there they drove to Elizabeth Bay to call on W. S. Macleay. "The ride from Sydney to South Head", Dana wrote later (*op. cit.*, p. 450), ". . . may be recommended as offering strong attraction to the lover of the beautiful in nature, especially as the noble bay throws its own life into many of the fine views". Alexander Macleay's home, set in its spacious garden of rare shrubs and creepers, flowers and imported trees, afforded delight to many visiting scientists to New South Wales. Yet, from their own records, it appears that the geologists found keener satisfaction in the coal traces they identified in the rocks behind the garden and in the ripples of sand shale on the shore

than in the botanist's paradise of the home at Elizabeth Bay (Clarke, Diary, 23 Dec. 1839 ; Dana, 1849, p. 461).

On Boxing Day, the ships of the United States Exploring Expedition weighed anchor and stood to sea to begin their cruise of the Antarctic. James Dana, however, with other members of the scientific corps, remained behind, and it was during these next two months of leisure in the Colony that his major geological work was done. At the beginning of the New Year, he travelled to Wollongong by steamer with the Expedition's artist, Mr. Drayton, and here on 2nd January Clarke joined them, riding overland from his rectory at Parramatta in anticipation of meeting his friends. During the several days the two geologists spent in Wollongong, they closely examined the coastline, where they found fossils of shells and wood in abundance in the argillaceous sandstone cliff ; they found also a raised beach in which they marked *Trochus australis*. On their last evening they were invited to attend a corroboree of tribes drawn from as far afield as Moreton Bay, and Clarke in his Diary records his " feelings of wild sublimity as fire after fire blazed up and I found myself among at least one hundred native savages in a state of perfect nudity and looking most unearthly " (Clarke, Diary, 6 Jan. 1840).

Next day they were on their way to Kangaroo Valley in the company of a guide. Clarke has left a lively record of this excursion on horseback through the fertile valleys and steep defiles, where the richness of the forest made " a sort of moonlight " and the shadowy groves offered a cool retreat from the midsummer heat. " This bush riding has quite an air of romance about it " he recounts in his Diary (7 January 1840).

> You gallop along over a green but not level turf, studded with splendid trees through which you wind your way . . . Suddenly you come upon some dry water course with lofty banks, the bed of which is strewn with large fragments of rocks over which and through which one must ride . . . Then, again, you cross rivers full of water, gliding along under a canopy of branches and having a thick jungle of ferns upon their edges, affording spots of most cooling aspect amidst the sultry heat of a noon-day . . . Occasionally we had to leap innumerable trees fallen across [the route] so that the ride had more of the character of a steeple chase than anything else and frequently recalled to my mind our boyish game of " follow the leader " as we saw the stockman guide cantering along in the van without slackening his speed, over this, through stumps, suddenly disappearing down a steep hump and then suddenly rising again up the opposite bank.

In this fashion they crossed the Macquarie River and ascended the rapidly rising slope of Illawarra mountain to the vertical wall of rock which topped its last three hundred feet. Here, clambering " on all fours sometimes, dragging our horses after us, we gained the summit, where we had a splendid view of the lake and sea and mountains and the deep defiles with thick forests which we had passed. Just at the summit we passed a trap dyke " (Clarke, Diary, 6 Jan. 1840).

By nightfall, they had made the zigzag descent into Kangaroo Valley which Dana characterized as " a narrow patch of land . . . scarcely averaging three miles in breadth, lying between abrupt mountain walls, from one thousand to eighteen hundred feet in height " (Dana, 1849, p. 452). Dana, Clarke reported, thought the sea had occupied the valley " as a gulph " but he had abandoned this false deduction when he came to write up his Report on the Geology of New South Wales. Clarke's own opinion was that it had recently been a fresh water lake from which the barriers had been burst. In Kangaroo Valley the travellers were received hospitably at Mr. Meare's station where, reassured by the comfort of a great log fire, they slept soundly after their long ride. Neither mosquitoes nor bugs, Clarke was happy to report, troubled their repose ; " a few fleas only danced a welcome to the Kangaroo Grounds ".

During the next days, Dana and Clarke were engaged in an intensive exploratory investigation—the first to be undertaken in any detail—of the Illawarra region from Broughton's Head to Coolangatta Mountain and along the coast to Black Head and Kiama ; a spectacular area of basalt interstratified with the sandstone and cutting the shoreline in deep, intersecting dykes. At Broughton's Head they came upon the " trap ", " the very rock ", wrote Clarke, " we had been in search of ", and they were to trace its outcrop in the Coolangatta Mountain down to a deep dyke running through the beach at Black Head. The two men evidently differed in their opinion of " trap ". Clarke reports an argument with Dana over a particularly hard specimen found at the river mouth at Black Head " but we at last agreed that it was true trap ". Dana wrote later, " It is doubtful whether the igneous rocks under

consideration are wholly *basalt*, or are in part *trap*, that is, whether they always contain augite with the feldspar or sometimes hornblende. Some ambiguous rocks may be referred to either variety" (1849, p. 497). He himself adopts basalt throughout his Report.

At Black Head they came upon the rich fossil beds of shells and wood which they had met earlier at Wollongong. "Our surprise was great", Clarke noted, "to find the whole of the low cliff which forms Black Head and the flat rocks below filled out with innumerable concretions as at Wollongong, shells and corralines and with masses of granitic and porphyritic rock embedded and divided by iron seams in every direction. Many of the shells were completely agatered." Here too they found a fossil tree, whose exposed part measured three feet long by seven inches wide.

Although many had seen the Blow Hole at Kiama by 1839, Dana and Clarke were the first to observe and record this phenomenon in geological terms (Clarke's long diary entry is recorded by Jervis, 1945, p. 34). Both men sketched the columnar basalt rising in beautiful order from the sea (Dana's elegant sketch is reproduced in his Report), and both pronounced it the very Staffa of New South Wales. The wildness of the coastal scenery where the sea hollowed out the basalt flows and dykes and hammered noisily against the narrow channels it had carved clearly attracted the two men and Dana writes evocatively of

> a dark cavern, eight or ten feet high, [which] extends into the cliff a hundred yards or more. The sea dashes in below and may be heard hurrying on, for a while becoming nearly still—when suddenly a sound like thunder roars through the cavern as the water strikes the farther walls, and a few rays of light are seen amid the darkness, sparkling from scattered foam (Dana, 1849, p. 496).

At Kiama the two geologists parted; Clarke to find his way overland through the Illawarra Mountain back to Parramatta; Dana to travel a short distance south, returning along the coast to Bulli and Mount "Keerah", where he examined the coal measures before turning inland to complete his homeward journey by way of Appin and Campbelltown. On 16 January he reached Clarke's home at Parramatta and the following day rode out with his friend to inspect the Prospect intrusion. It was Clarke's last Diary entry about the American. "Mr. Dana and I rode to Prospect . . . Examined the basalt and traced a dyke of syenite, black and hard all along the ridge" (Clarke, Diary, 17 Jan. 1840; cf. Dana, 1849, p. 516).

From his own evidence, Dana appears to have spent the remainder of his stay in the Colony in the Hunter River District in a meticulous investigation of the coal deposits at Nobby Island and Telegraph Hill, and at Lake Macquarie. From James Steel, Superintendent of the Coal Works at Newcastle, he received substantial help, and he made the acquaintance of the Rev. C. P. Wilton, one of the early promoters of Australian science. Wilton was the founder and energetic president of the Newcastle Mechanics' Institute whose object was the encouragement of colonial science, and it was among the geological collection at the Institute that Dana saw the one fossil specimen of marine life found in the upper Newcastle coal beds. He himself observed none *in situ* and of the many plant remains he encountered in the formations he reports that the simple leaved *Glossopteris Browniana* made up four-fifths (1849, pp. 482–3).

By the middle of March 1840, the American Squadron had returned from the Antarctic, where the discovery of Wilkes Land commemorates their work, and after a week's refitting in Sydney, they sailed for New Zealand on March 19. The scientific members, followed aboard the *Peacock* a few days later, and, in the last stage of their journey were wrecked off the mouth of the Columbia River. The company, however, escaped in the boats with their reports and specimens and returned overland to Washington in June 1842.

It was not for ten years after his Australian visit that James Dana published his Report on the Geology of the Expedition, with its masterly chapter on the geology of New South Wales. In the same year of 1849, he was appointed to the Chair of Natural History at Yale. Despite the briefness of his visit, Dana made a number of important contributions to the foundations of Australian geological science. Having travelled with him through the basaltic region of the Illawarra it is instructive to turn to the highly lucid account he has left of this fortnight's geological reconnaissance which provided a firm starting point for later detailed surveys of that area.

> The basaltic rock occurs both in layers interstratified with the sandstone, and in dikes. By its occurrence, both underlying some layers below the coal, and also protruding through the Sydney sandstone,

it appears to be of different ages. The alternation of sandstone and basalt may be seen in many of the cliffs from Black Head to Point Bass, six miles north of Kiama . . . At Black Head, the basalt does not occur in the cliff itself, but may be seen overlying the argillaceous sandstone a few hundred yards back. Going to the northward from this cape, the basalt soon appears capping the bluffs, and dipping with the sandstone below to the northward and westward. This layer of basalt, further north, dips to the water just north of Stony Cove, three miles south of Kiama, where the lower sandstone layer is no longer in sight. The next bluff north is wholly basaltic. The next beyond is capped with red sandstone ; this rock does not appear on the following cliff (at Kiama), which is very low, but composes the whole of the next one, with the exception of a small basaltic portion near the water's surface at the south end. The basalt thus dips beneath the water like the layer of sandstone before mentioned. Continuing our course northward, in the next cliff, the sandstone becomes capped with a second layer of basalt. Farther on the sandstone disappears and leaves the basalt alone.

There are hence, in this coast section, two distinct layers of sandstone, and two of basalt interstratified with them ; they disappear in succession as we go northward from Black Head, excepting the upper basalt (Dana, 1849, p. 499).

More important however were the conclusions Dana formed from his examination of Kangaroo Valley of the origins of the deep walled gorges of New South Wales. Writing five years after the publication of Darwin's thesis that these gorges were original escarpments of the sandstone (Darwin, 1844), Dana dismissed Darwin's conclusion and argued for the effects of running water in denuding the soft rock over long periods of geological time. In doing so he substantially anticipated modern views of valley making in New South Wales.

It is, however, in his observations of the coal measures of the Colony that Dana made his most enduring contribution to the geology of New South Wales. Publishing a decade after the collection of his material it was inevitable that he was anticipated to some extent, but his stratigraphical and lithological descriptions of what he called the " Sydney sandstone ", the coal formation and the sandstone below the coal from the Hunter Basin to Wollongong and Dapto, indicate the extraordinary grasp and accuracy of Dana's evidence and the penetration he was able to bring, even as a very young man, to his geological work. The palaeontological findings of others, notably Morris, Lonsdale and McCoy, he incorporated in his Report.

Significantly, Dana's evidence appeared at a time when serious conflict had developed in geological circles on the age of Australian coal. Dana's former companion, W. B. Clarke, from his own extended researches in the Colony, challenging the widely held view that Australia was a country of recent geological age, had asserted the greater age of the Illawarra and Newcastle coal formations of New South Wales than those of Europe and India. He assigned them to the Devonian or lower Carboniferous ; and he further argued that the marine beds of fossiliferous sandstone underlying the coal and those of predominantly plant fossils above were conformable with the coal seams and belonged to the same geological period. (Evidence before N.S.W. Legislative Committee on Coal, 1847, and published note, 1848.) But the Cambridge palaeontologist, Frederick McCoy, from the evidence of Clarke's own fossils from the Illawarra and the Hunter, insisted that a vast interval of geological time separated the lower Carboniferous marine deposits beneath the coal, the coal seams themselves and the beds above whose plant fossils, he considered, most nearly resembled the coal fields of India and the true Oolitic fields of Europe. McCoy's verdict rested on the absence of animal remains in the upper beds of sandstone. From his sanctuary at the Woodwardian Museum he maintained, and was to continue to maintain for many years after he came to Australia to assume the Melbourne University Natural History Chair, that the lower marine beds and the beds of plant fossils above the coal were not conformable and belonged to widely different geological systems (McCoy, 1847).

Into this arena of conflict, Dana brought positive evidence from his own observations in the Colony of the conformability of the Australian coal beds. Both in the Illawarra-Wollongong area and at Nobby and Telegraph Hill, he had found the sedimentary deposits below and above the coal conformable and passing in gradual transition into one another in an unbroken series (Dana, 1849, pp. 459, 484).

He supported the earlier judgment which Morris had given on Strzelecki's specimens in 1845, that the flora of the southern hemisphere differed from the northern at the " carboniferous period " (Strzelecki, 1845). Louis Agassiz,

moreover, in his identification of Dana's reproduction of the Newcastle fossil fish found in the overlying sandstone, referred it to the upper Carboniferous or transition Permian, and in Dana's analysis, this best accorded with the observed facts. Dana therefore concluded his survey of the N.S.W. coal deposits in the following terms (1849, p. 495) :

> While the coal plants point to the upper carboniferous, or still higher, the fossils below the coal seem to correspond most perfectly with the lower carboniferous epoch. Yet the conformity and continuity of the series of beds, (including the sandstones below the coal, and the coal layers) observable in various places, the frequent occurrence of conifer logs, like those of the coal beds, in the fossiliferous sandstones at different localities, together with the characters of the fossil fish, leave little doubt that the whole is of one prolonged age, referable to the upper carboniferous, or partly the lower Permian era.

It was an accurate and timely contribution to the elucidation of the history of the Permo-Carboniferous systems in New South Wales.

As soon as W. B. Clarke read Dana's Report, he wrote at once to his old friend to compliment him on his work and to re-establish contact between them. Dana's reply from New Haven is dated 1 September 1851 (W. B. Clarke Papers).

> I was much gratified with the reception of your excellent letter of 19 December last, and glad to feel assured that we might carry on a correspondence although half the globe lies between us. It was a pleasure to know that with all your opportunities for investigation so thoroughly pursued, you find reason to confirm in the main the ground I have taken respecting New Holland geology. My time there was short, but it was spent most agreeably and most instructively to myself ; and that Illawarra District is a perfect gem of a place for Geology as well as for landscape beauty ; it is one of the loveliest spots on the Globe. I shall look forward with great interest for the published account of your labours, in which you have made so many and important discoveries.

Of McCoy's work, Dana observed a tactful restraint. " I was satisfied McCoy had made some errors as to localities ", he commented. " You will set us all to right in whatever is wrong through haste, inadvertence or imperfect knowledge . . . Those places we visited together are remembered by me with deep feelings of pleasure."

James Dana's next letter to Australia is dated 1854. He had followed some accounts of Clarke's recent researches into the gold fields of New South Wales, and looked forward to receiving the Report which Clarke had promised him.

> I trust you will reap some golden results from your labours on behalf of the Gold in Australia. I should enjoy very much another ride over the hills and through the valleys of the country. Will you never come to Yankee land ? I should be much pleased to see you here. I wish that you would write a work on the geology of New South Wales and publish it at Government expense. I know you have had this in view. And how long before it will be accomplished ? You must have a vast amount of material for such a work, and it would make a most valuable contribution to Science—Australia is the land for queer things, and therefore a grand place for Scientific Exploration. I should rejoice to take it up with you if and if—and if—there are three ifs, and one long one beside.

Clarke had sent Dana a drawing of a fossil fish from Parramatta which the American geologist had forwarded for identification to Agassiz. The enclosed reply to Dana, found among the Clarke Papers, is in Agassiz's hand, and reports that the aging palaeontologist had journeyed to Cambridge, Massachusetts, to consult his own work on fossil fishes " not having looked at the subject for many years and wanting to give a precise answer to the enquiries of Mr. Clarke, as the subject is so highly interesting ". Agassiz identified the fish positively as belonging to the Oolitic series. " I am satisfied ", he wrote, " they are of more recent date than he [Clarke] supposes. This would however render his investigations only more important in a geological point of view."

Dana's own opinion on the age of the Australian coal measures was to undergo some change as later fossil evidence came to light. In a letter to Clarke of 15 January, 1858, he observed, " I think you will have to lift the Australian coal measures up to the Triassic at least. The Illawarra fossils below the coal may be Permian, and the coal itself Triassic." " How I should enjoy another stroll over your hills and into your valleys ! " he concluded this letter, " But I have done roaming."

It was a theme that was to run through all Dana's letters to New South Wales. As late as 1872, he confided to his old friend, "The few weeks of intercourse which I had with you in Australia were amongst the happiest days of my life and I shall never forget your kindness, or the scenes we enjoyed together". Danas last letter is dated 3 January 1876 ; Clarke was then 78 and within two years of his death. It was thirty-six years, Dana reminded him, since they had met, and he closes their long correspondence with words which marked his own firmly held faith in the purposes of God : " . . . the verses you enclosed and for which I thank you, show that you are ready for whatever is in store, having that blessed hope that makes even death a victory."

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Lower Carboniferous Faunas from Wiragulla and Dungog, New South Wales

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Abstract—The Middle to Upper Viséan (Cu III$_{\alpha-\beta}$) faunas from Wiragulla and Dungog are examined and their palaeoecology discussed. The stratigraphy of the Wallarobba-Dungog district is briefly considered, including a first description of the Wiragulla Beds which occur between the Ararat and Wallaringa Formations on the eastern limb of the Wallarobba Basin. Species described are : *Chonetes cangonensis* n.sp., *Gigantoproductus tenuirugosus* n.sp., *Inflatia elegans* n.sp., *Echinoconchus gradatus* Campbell, *Athyris wiragullensis* n.sp., *Spirifer osbornei* n.sp., *Kitakamithyris* sp., *Balanoconcha elliptica* Campbell, *Streblopteria* sp., and *Aviculopecten* sp.

Introduction

Marine fossils were first collected in 1960 from the Dungog and Wiragulla localities during geological investigations in the Wallarobba-Dungog district. No previous record of collections from either locality has been found in the literature, although Benson (1921) gave Dungog as a Carboniferous fossil locality. However, a more precise locality was not defined and from a search of the literature it now appears that he referred to several different localities, all of which were south of those dealt with in this work.

Grid references quoted in this paper are taken from the Dungog One Mile Military Sheet. All fossil and locality numbers refer to the palaeontological register at the University of New England, Armidale, N.S.W.

The L.235 Dungog fossil locality is situated 3 miles south of Dungog, three-quarters of a mile west of the main Dungog-Maitland road, and the L.234 Wiragulla locality occurs immediately north-east of Wiragulla railway siding, approximately 4 miles south of Dungog (Text-fig. 1). A northward extension of the L.234 horizon crops out 150 feet stratigraphically above the L.235 Dungog locality.

Both horizons are particularly important because they are contained in stratigraphic sections which extend into the non-marine Wallaringa Formation. The occurrence of *Delepinea aspinosa* (Dun) on both horizons suggests that they can be correlated with one 800 to 1,000 feet above the base of the "Lower Kuttung Series" in the Rouchel Basin (Campbell and Roberts, 1964 in press).

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Regional Stratigraphy

The geology of the Gresford district has been considered in a previous paper (Roberts, 1961). Text-figure 2 illustrates the stratigraphic nomenclature of the formations in the Gresford-Dungog district. The stratigraphy of the district is briefly summarized below.

The Bingleburra Formation (approximately 3,000 feet in thickness) consisting of mudstones, siltstones, oolitic and crinoidal limestones and interbedded sandstones and conglomerates, is overlain by the Ararat Formation (1,500 feet in thickness). This formation is composed of calcareous tuffaceous sandstone with minor mudstones and oolitic and crinoidal limestone lenses.

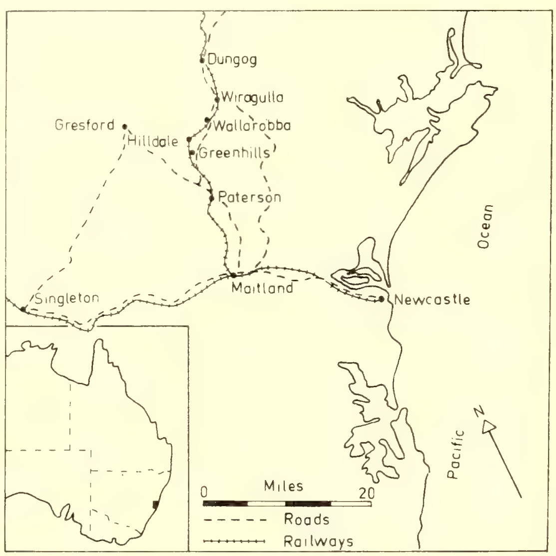

Fig. 1

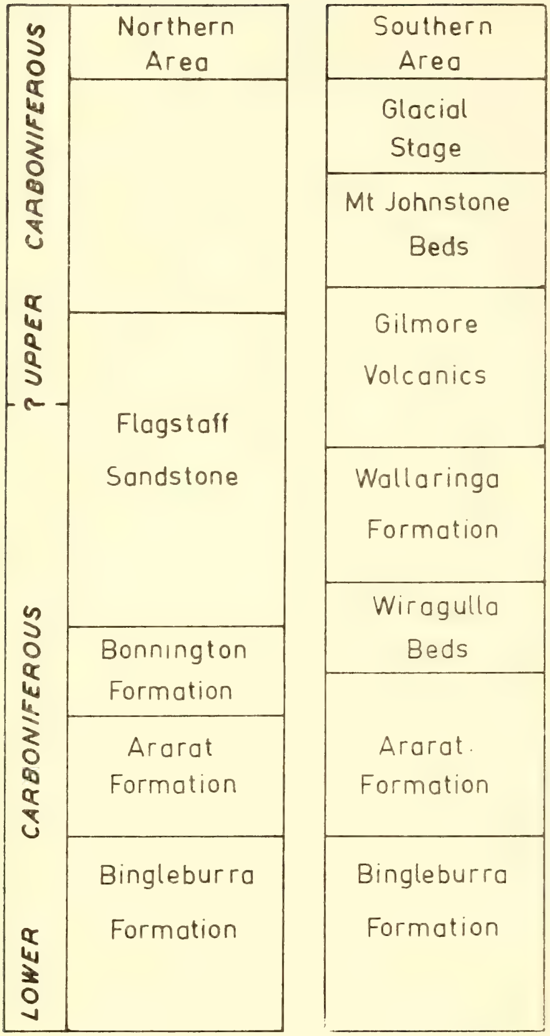

Fig. 2

Following Ararat sedimentation marine conditions continued without interruption in the north of the area, and the Bonnington Formation (400 feet in thickness), consisting of siltstones and mudstones, underlies the coarse tuffaceous Flagstaff Sandstone (5,500 feet in thickness).

To the south, following the deposition of the Ararat Formation, conditions changed in parts to a non-marine environment due to the uplift of a narrow belt stretching from Hilldale to Mt. Ararat (Roberts, 1961). However, away from the influence of the uplift, for example at Wiragulla near Dungog, a thin marine mudstone and siltstone sequence (Wiragulla Beds) is interbedded between the Ararat Formation and the non-marine Wallaringa Formation. The Wallaringa Formation (950 feet in thickness) is overlain by the Gilmore Volcanics, the Mt. Johnstone Beds (Sussmilch and David, 1920) and rocks of the Glacial "Stage" (Osborne, 1922).

Local Stratigraphy

Sediments exposed in the Wiragulla-Dungog district crop out on the eastern limb of the Wallarobba Basin. The geology of the district is illustrated in Text-figure 3 and a stratigraphic section from the eastern limb of the basin given in Text-figure 4.

Rocks of the Bingleburra Formation crop out a short distance north of the area dealt with in this paper and are overlain by those of the Ararat Formation. Faunal evidence suggests that Ararat sedimentation in the Dungog district may have been prolonged compared with that further to the north and that the Ararat Formation is a time-transgressive unit. Faunas containing *Delepinea aspinosa* (Dun) occur in the upper beds of the Ararat Formation and the lower part of the overlying Wiragulla Beds on the eastern limb of the Wallarobba Basin. A fauna in the basal beds of the Bonnington Formation, which overlies the

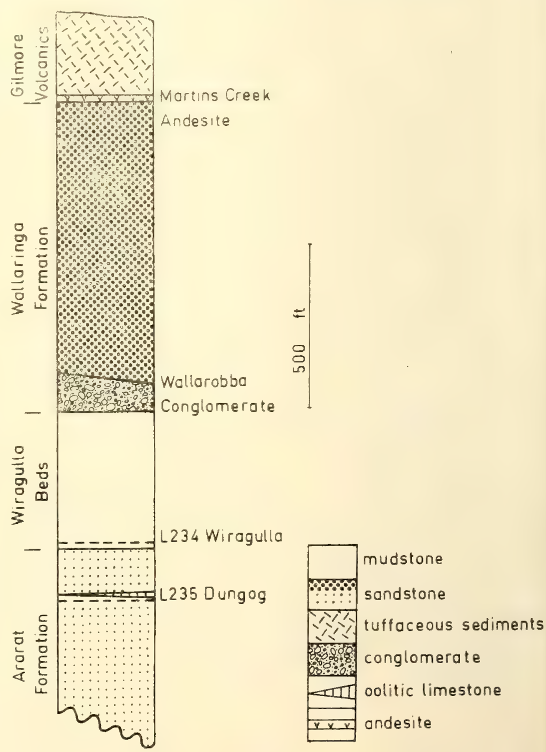

Fig. 4

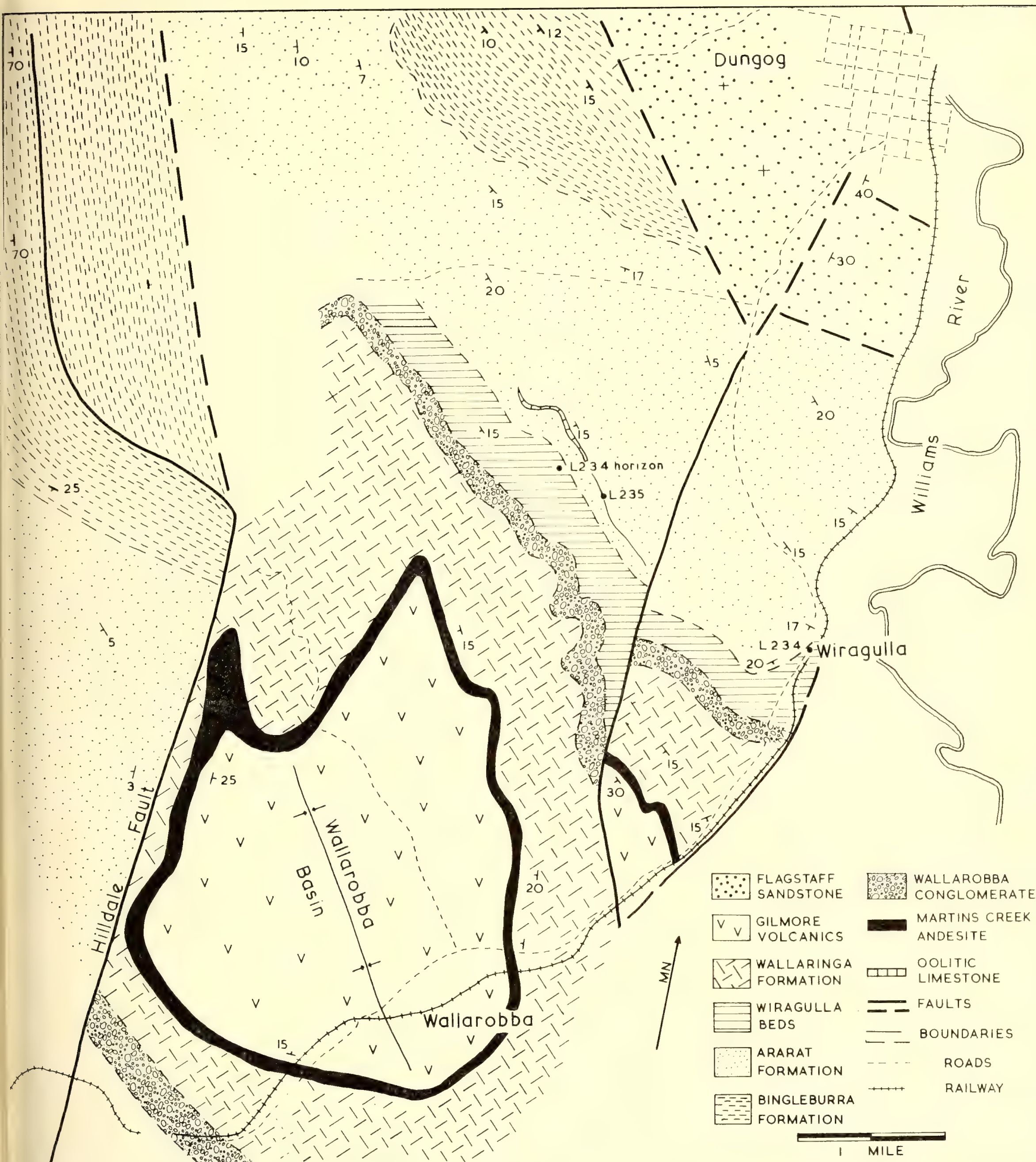

Fig. 3

Ararat Formation in the Lewinsbrook Syncline 10 miles to the north-west, is distinctly older and is more closely related to the Middle Viséan (Cu III$_{\alpha}$) L.53 Greenhills assemblage (Roberts, 1964).

The Wiragulla Beds occur in an area south of Dungog where they occur between the Ararat and Wallaringa Formations. The Wallaringa Formation crops out strongly on the hills forming the eastern flank of the Wallarobba Basin and is overlain by the Martins Creek Andesite, the basal member of the Gilmore Volcanics. Tuffaceous sandstones belonging to the Gilmore Volcanics crop out in the centre of

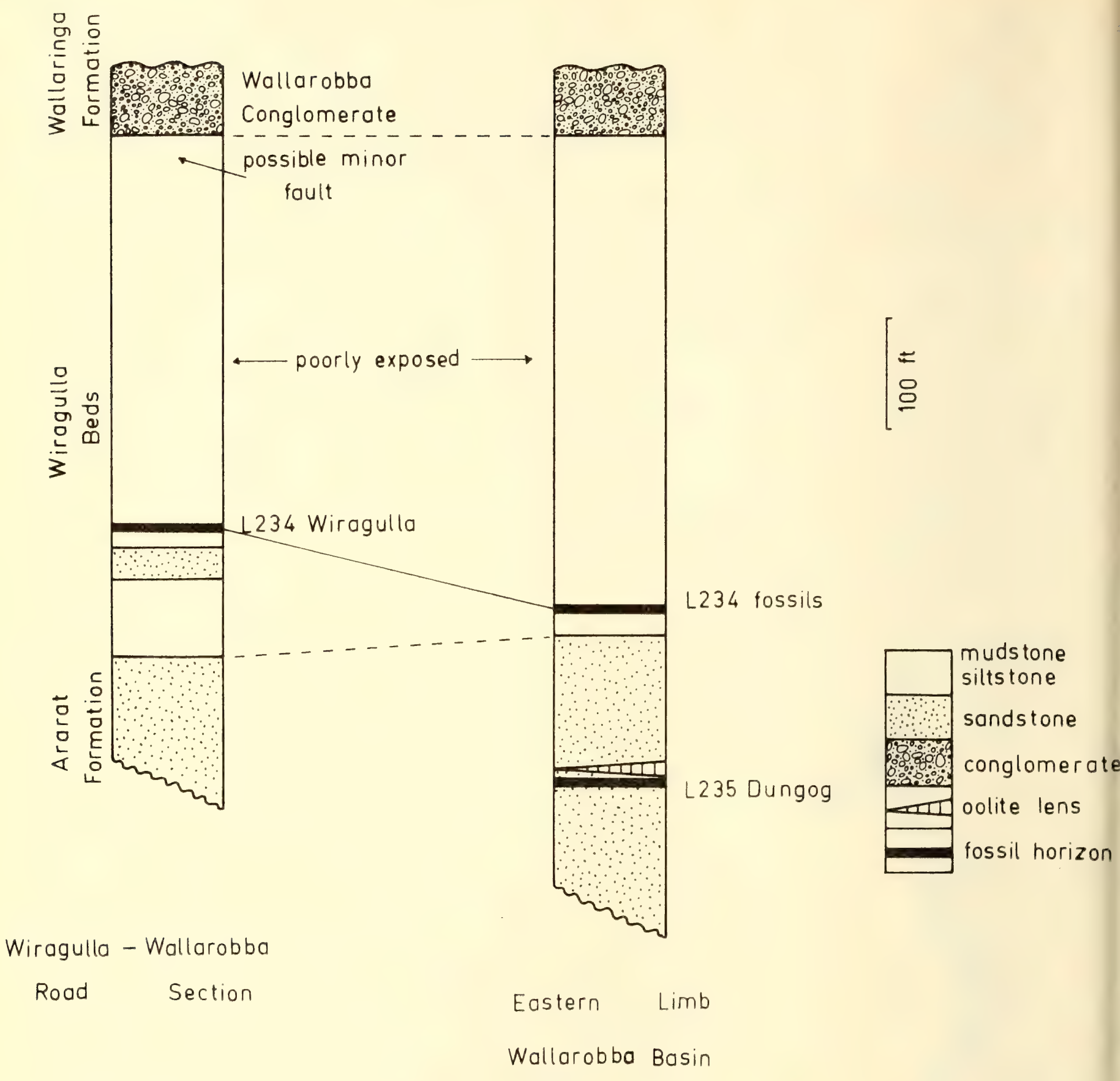

Fig. 5

the Wallarobba Basin. To the north of the basin the coarse marine Flagstaff Sandstone interfingers with and replaces the non-marine Wallaringa Formation.

Wiragulla Beds

The best exposed section of the Wiragulla Beds crops out on the north-western side of the Paterson-Dungog road from 47659862, near the overhead road bridge crossing the North Coast Railway Line, to approximately 47609852 (Text-fig. 5). A small fault causes a slight disruption to the upper parts of this section immediately below the Wallarobba Conglomerate near a roadside quarry at 47609852. The remainder of the section is influenced by a fault running along the south-eastern side of the railway line and has an anomalous dip to the south. The base of the Wiragulla Beds rests on massive sandstones of the Ararat Formation cropping out to the west of the Chichester-Newcastle water pipeline. The upper limits are obscured by the small fault mentioned above, but the beds appear to gradually merge into coarse sandstones at the base of the Wallarobba Conglomerate.

A more poorly exposed section occurs approximately 2 miles north-west of the road section

on the eastern limb of the Wallarobba Basin (Text-fig. 5). Here, the Wiragulla Beds conformably overlie the Ararat Formation and pass with apparent regular conformity into the overlying Wallaringa Formation.

Thickness. The thickness of the Wiragulla Beds is approximately 450 feet.

Lithology. For the most part the Wiragulla Beds are composed of distinctive grey to pale fawn mudstones and fine-grained sandstones.

Lateral Variation. (1) The Gresford District. Two occurrences of the Wiragulla Beds are known from the Gresford District, but because of very poor exposures and the complex nature of the regional stratigraphy they have previously been mapped with other formations. (*a*) The L.210 Toryburn fossil locality, found in an isolated outcrop on the bank of McIntyre's Creek, is surrounded by a large area of alluvium and has been included in the Wallaringa Formation in the geological map of the Gresford district (Roberts, 1961). (*b*) A thin sequence of fossiliferous mudstones containing the L.211 fossil locality (Roberts, 1961) underlies massive green sandstones on the south-western side of the Colstoun Basin near the Gresford Fault. These mudstones were previously mapped with the Flagstaff Sandstone, but their stratigraphic position and lithology appear to link them with the Wiragulla Beds.

(2) South-western margin of the Wallarobba Basin. In a newly exposed section in a road cutting across the Wallarobba Range the Wiragulla Beds are missing, and coarse-grained lithic sandstones appear to underlie the Wallarobba Conglomerate conformably. The absence of the Wiragulla Beds, however, can possibly be best explained by the existence, in certain areas, of an unconformity at the base of the Wallaringa Formation. Support for this suggestion comes from the Clarencetown district, where the Wiragulla Beds and faunas characterised by *Delepinea aspinosa* (Dun) are absent from beneath the Wallarobba Conglomerate; instead, the latter member is underlain by a sequence containing a Middle Viséan ($CuIII_{\alpha}$) fauna, the same as that found at L.53 Greenhills (Roberts, 1964), which is definitely older than the $CuIII_{\alpha-\beta}$ assemblages from Wiragulla and Dungog.

The sandstones underlying the Wallarobba Conglomerate in the above section are coarse-grained, contain a high percentage of volcanic rock fragments, and have a dark green chloritic cement. They are usually massively bedded, but exhibit small scale cross stratification on a number of horizons. The lithology changes markedly near the base of the Wallarobba Conglomerate Member from a dark green chloritic sandstone to a pink zeolitic rock. In the lower parts of the western flank of the range the sandstones are accompanied by several thin conglomerate bands.

Fossil Localities

The stratigraphic positions of the fossil localities discussed in this paper are illustrated in diagrammatic stratigraphic sections from the eastern limb of the Wallarobba Basin (Text-figs. 4, 5).

L.235 Dungog occurs in a calcareous sandstone and impure limestone at grid reference 47439880, on the top of a ridge three-quarters of a mile west of the Dungog-Maitland road. Stratigraphically this horizon occurs 130 feet below the top of the Ararat Formation. The fossil bed can be traced some distance north and south of the L.235 collecting point and its lateral extent is shown in Text-figure 3.

L.234 Wiragulla is found in pale fawn fine-grained siltstones cropping out on the roadside opposite the large gates of Wiragulla railway siding (grid reference 47659861) and in the railway cutting immediately north-east of the siding. L.234 occurs towards the base of the Wiragulla Beds, its stratigraphic position being shown in Text-figure 5. A northward extension of the L.234 horizon has been found approximately 150 feet stratigraphically above L.235 Dungog.

The stratigraphic sections on the eastern limb of the Wallarobba Basin have enabled the L.234 and L.235 horizons to be placed in a sequence extending upwards into the Wallarobba Conglomerate Member of the Wallaringa Formation, the Basal unit of the Kuttung Group.

Dungog and Wiragulla Faunas

The following is a list of all identifiable species collected during the present investigation. Those forms described in this paper are marked with an asterisk.

L.235 Dungog.

Fenestella sp.
Leptagonia cf. *L. analoga* (Phillips)
**Chonetes cangonensis* n.sp.
Delepinea aspinosa (Dun)
**Gigantoproductus tenuirugosus* n.sp.
**Echinoconchus gradatus* Campbell
Waagenoconcha delicatula Campbell
Inflatia simplex (Campbell)
Pustula sp.

Unispirifer striatoconvolutus (Benson and Dun)
Voiseyella anterosa (Campbell)
Kitakamithyris sp.
**Balanoconcha elliptica* Campbell
**Aviculopecten* sp.
**Streblopteria* sp.
Diodontopteria delicata Roberts
Tentaculites sp.
Straparolus sp.

L.234 Wiragulla.
Fenestella sp.
Conularia sp.
Schizophoria verulamensis Cvancara
Delepinea aspinosa (Dun)
**Inflatia elegans* n.sp.
**Spirifer osbornei* n.sp.
**Athyris wiragullensis* n.sp.
**Kitakamithyris* sp.
Stenoscisma laevis Roberts
Diodontopteria sp.
Bellerophon sp.
Straparolus sp.
Tentaculites sp.

L.234 continuation, 150 feet stratigraphically above L.235.
Schizophoria verulamensis Cvancara
Leptagonia cf. *L. analoga* (Phillips)
Schuchertella concentrica Roberts
Delepinea aspinosa (Dun)
**Chonetes cangonensis* n.sp.
Waagenoconcha delicatula Campbell
**Echinoconchus gradatus* Campbell
Fluctuaria campbelli Roberts
**Inflatia elegans* n.sp.
**Spirifer osbornei* n.sp.
Unispirifer striatoconvolutus (Benson and Dun)
**Athyris wiragullensis* n.sp.
Cleiothyridina sp.
"*Camarotoechia*" sp.
Stenoscisma laevis Roberts
**Balanoconcha elliptica* Campbell
**Aviculopecten* sp.
Bellerophon sp.

The following species have restricted vertical ranges and in the Gresford-Dungog district are confined to the L.235 and L.234 assemblages: *Delepinea aspinosa* (Dun), *Chonetes cangonensis* n.sp., *Gigantoproductus tenuirugosus* n.sp., *Inflatia elegans* n.sp., *Inflatia simplex* (Campbell), *Spirifer osbornei* n.sp., *Athyris wiragullensis* n.sp., *Balanoconcha elliptica* Campbell, *Aviculopecten* sp., *Streblopteria* sp. These constitute a faunal element which is distinct from the younger assemblages in the district (Roberts, 1963, 1964, 1965).

Age of the Fauna

The age of the Wiragulla-Dungog fauna can be closely estimated as Middle to Upper Viséan (Cu $III_{\alpha-\beta}$). It is younger than the Middle Viséan (Cu II_{δ} to Cu III_{α}, Brown, Campbell and Roberts, 1964) fauna from Trevallyn described by Roberts (1965 in press), and the Middle Viséan (Cu III_{α}) fauna from Greenhills (Hilldale) described by Roberts (1964).

An age closer to Middle Viséan is suggested by the presence of *Schuchertella concentrica* Roberts, *Echinoconchus gradatus* Campbell and *Voiseyella anterosa* (Campbell) in the Greenhills fauna, and *Echinoconchus gradatus* Campbell, *Inflatia simplex* (Campbell), *Voiseyella anterosa* (Campbell) and *Balanoconcha elliptica* Campbell in the Babbinboon fauna from the Werrie Basin. The latter fauna is now considered to be at the latest Middle Viséan in age, this determination being based on the presence of Upper Tournaisian goniatites in the lower part of the Carboniferous sequence in the Werrie Basin (Campbell and Engel, 1963), and on a correlation of the Babbinboon horizon with the Burlington and Keokuk Limestones of North America. Recent work by Collinson, Scott and Rexroad (1962) has shown the Burlington and Keokuk Limestones to be correlated with the Cu $II\gamma$ and Cu II_{δ} zones, respectively, of Germany.

Two brachiopod relationships may be considered in detail. *Voiseyella anterosa* (Campbell) is morphologically close to *Spirifer mundulus* Rowley from the Lower Burlington Limestone of the Mississippi Valley, U.S.A. (Campbell, 1957). This again suggests a Middle Viséan age.

Gigantoproductus tenuirugosus n.sp. appears to be morphologically similar to *G. dentifer* (Prentice), which ranges from the C_2S_1 zone to the D_2 zone in England and is most common in the D_2 of Derbyshire. In Belgium *G. dentifer* occurs in rocks of V_{3a} age.

Preservation and Palaeoecology

L.235 Dungog. Shelly material is present in all except the extensively weathered portions of the calcareous sandstone and impure limestone constituting this horizon. The weathered portion of the rock is most useful in determining internal structures but is extremely friable. Leaching of unweathered material with hydrochloric acid is a difficult process because of the calcareous nature of the rock.

L.234 Wiragulla. Fossils from this locality are preserved as internal or external moulds in

a grey to fawn mudstone. Little trace of shell material has been found.

The following observations give some indication of environmental conditions prevailing during the accumulation of the two fossil beds.

L.235 Dungog.

(1) The L.235 horizon is characterized by an intermixed brachiopod/pelecypod fauna, brachiopods being in the majority. Polyzoa are rare and where found are always fragmentary. Solitary corals are absent.

(2) *Chonetes cangonensis* n.sp. and *Gigantoproductus tenuirugosus* n.sp. always have broken hinge spines, suggesting that the shells had been washed around by current action. However, the external features of the shells examined are well preserved, show no evidence of abrasion, and some forms, such as *Echinoconchus gradatus* Campbell and *Pustula* sp., still retain their delicate external spinose ornament.

(3) A considerable amount of fragmentary shell debris, particularly pieces of *Gigantoproductus tenuirugosus* n.sp. shell, is found in parts of the bed.

(4) Valves of brachiopods and pelecypods are usually found dissociated, having been washed apart after the death of the animal.

(5) The population ranges from juveniles to adults and species of all sizes occur in the one bed. No major sorting appears to have taken place.

(6) Although the bottom sediment apparently had no suitable hard areas where brachiopods possessing a pedicle could anchor themselves, many specimens of the terebratuloid *Balanoconcha elliptica* Campbell have been collected. These show no evidence of having been washed into the bed from elsewhere and presumably attached themselves to other shelly organisms.

The L.235 fauna appears to be near its original position of growth in a shallow sandy marine environment. Occasional stronger currents washed in fragments of *Gigantoproductus tenuirugosus* n.sp. which may have been broken by wave action in a region nearer the shoreline. Despite the disarticulation of the valves, most other species are probably somewhere near their original position of growth because they are unsorted and their surfaces are well preserved and show no indication of abrasion. A rapid burial soon after death may account for the preservation of the delicate ornament on some spinose brachiopods.

L.234 Wiragulla.

(1) Most shells are disarticulated and often have worn external surfaces. Productid brachiopods are stripped of all external spines. Internal features, however, are excellently preserved. Solitary corals are not found in their positions of growth but lie parallel with the bedding planes. Polyzoa are rare.

(2) Portions of the fossiliferous bed contain a mass of broken gastropod fragments, ostracods, broken echinoid plates and spines and crinoid columnals. The sediment accompanying the fragmentary material is noticeably coarser than the remainder of the bed and may have been washed in by stronger current action.

(3) Sorting has taken place to a limited extent and though the population ranges from juveniles to adults the latter predominate.

(4) Wood fragments are common.

(5) The finer sediment contains fragmentary burrows formed by a sub-surface fauna.

The L.234 Wiragulla fauna is not preserved in a living position. The wear shown by the exteriors of the larger productid and spiriferid shells, the disarticulated nature of the valves and the absence of productid spines suggests that currents washed the shells around for a considerable time prior to burial. Fragmentary debris associated with slightly coarser sediment may have been carried in by stronger currents.

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SYSTEMATIC PALAEONTOLOGY

Brachiopoda

Suborder CHONETOIDEA Muir-Wood, 1955
Superfamily CHONETACEA Shrock and Twenhofel, 1953
Family CHONETIDAE Bronn, 1862
Subfamily CHONETINAE Bronn, 1862
Genus CHONETES Fischer de Waldheim, 1830

TYPE SPECIES: *Terebratulites sarcinulatus* Schlotheim, 1820, by subsequent designation of Verneuil, 1845.

DIAGNOSIS: An emended diagnosis for the genus has been given by Muir-Wood (1962).

REMARKS: This material is referred to *Chonetes* sensu stricto as redefined by Muir-Wood. The most characteristic features supporting this designation include the two poorly defined septa in the brachial valve, the strong median septum in the pedicle valve and the relatively flat nature of the shell. The transverse form of the shell is the only departure from the characters presented in the emended diagnosis.

Chonetes cangonensis n.sp.

Plate I, figs. 1–10

DIAGNOSIS: Shell flat to slightly plano-convex; twice as wide as long, sub-rectangular in shape with rounded cardinal margins; 20–24 capillae occur per 3 mm. at the anterior margin of the shell. Pedicle valve has 3 or 4 spines on either side of the umbo; median septum extends to the mid-point of the valve. Brachial valve possesses strong socket plates; 2 long divergent spinose septa extend from the muscle field almost to the anterior margin; a median septum has not been observed.

DESCRIPTION:

EXTERNAL. The shell is small, extremely flattened, approximately twice as wide as long, and sub-rectangular in shape. The greatest width occurs a short distance in front of the hinge and the lateral margins and cardinal extremities are well rounded. Capillae are narrow, half as wide as the well rounded separating sulci, and increase by more or less regular intercalation. There are 20–24 papillae per 3 mm. at the anterior margin of the shell. Concentric and radial micro-ornament is absent. The surface ornament becomes weaker on the postero-lateral margins of the shell. The dimensions of the largest shell observed are 10 mm. wide and 6·5 mm. long.

Pedicle valve is slightly convex on the postero-lateral slopes, but flattens anteriorly. The umbo is obsolete. Three or four spines are present along the hinge on either side of the umbo. An extremely faint median sinus may be developed. The cardinal area is flat and less than 0·5 mm. high at the umbo. No details of the delthyrium have been observed.

Brachial valve is flat and has a lower cardinal area than that of the pedicle valve. The fold is generally obsolete.

INTERNAL. Pedicle valve. The median septum is thin, extends from the umbo to the mid-point of the valve and tapers anteriorly to a sharp blade-like ridge. Two faint divergent ridges arise at the base of the septum and run a short distance laterally. They may border the muscle field. No details of the muscle scars or dental apparatus have been observed. The internal surface of the valve is ornamented with aspinose striae which tend to be irregular in the mid-portion of the valve.

Brachial valve. Socket plates are large, arise from the base of the cardinal process, curve laterally and are slightly divergent from the hinge. Two smaller divergent ridges run from near the base of the cardinal process and enclose the muscle field. The muscle field is triangular in shape and deeply depressed below the cardinal process. Individual muscle scars are not preserved. Two slightly divergent spinose septa extend from the base of the muscle field almost to the anterior margin of the valve. The septa are low and may be almost obsolete in some specimens. The internal surface is marked with papillose radial ribs having a density of 10–12 per 2 mm. at the anterior margin. Papillae are coarsest a short distance behind the margins of the valve. No details of the cardinal process have been observed.

REMARKS: A search of both overseas and Australian literature fails to reveal any *Chonetes* species which can be closely compared with *Chonetes cangonensis*. The Lower Carboniferous species *C. failandensis* S. Smith, figured by Muir-Wood (1962), is larger, has a more convex pedicle valve, a more concave brachial valve, a more globular shape and is more coarsely striate.

This species is named after the property "Cangon", situated 2 miles south of Dungog.

OCCURRENCE: *Chonetes cangonensis* has been collected from L.235 Dungog, the type locality, and a continuation of the L.234 Wiragulla horizon, 150 feet stratigraphically above L.235.

MATERIAL: F.7096–F.7108. *Holotype* F.7096a, *paratypes* F.7096b, F.7097, F.7102.

Suborder PRODUCTOIDEA Maillieux, 1940
Superfamily PRODUCTACEA Waagen, 1883
Family GIGANTOPRODUCTIDAE Muir-Wood and Cooper, 1960
Subfamily GIGANTOPRODUCTINAE Muir-Wood and Cooper, 1960
Genus GIGANTOPRODUCTUS Prentice, 1950

TYPE SPECIES: *Productus giganteus* J. Sowerby 1822.

Gigantoproductus tenuirugosus n.sp.

Plate I, figs. 11–19

DIAGNOSIS: Pedicle valve transverse, semi-elliptical and moderately convex; umbonal curvature weak; postero-lateral margins

flattened ; hinge-line long and ornamented with a single row of spines ; there are approximately 25 spines on either side of the umbo ; costellae have a density of 10–14 per 10 mm. at a distance of 20 mm. from the umbo. Brachial valve moderately concave and rugose.

DESCRIPTION :

EXTERNAL. Pedicle valve is wider than long, semi-elliptical in shape, inflated medially and has flattened postero-lateral margins. The greatest convexity occurs a short distance in front of the umbo. The umbo is pointed and does not incurve over the hinge. Lateral shoulders slope steeply to the flat lateral margins. The hinge-line is the widest part of the shell and is ornamented by a single row of closely spaced spines which increase in strength laterally. Approximately 25 spines are present on each side of the umbo. The trail is weak, the venter evenly rounded and the fold and sinus obsolete. Costellae are well defined and are twice as wide as the intercostal troughs. The costellae become broader towards the margins of the shell, increase by random intercalation and have a density of 10–14 per 10 mm. at a distance of 20 mm. from the umbo. They become wavy on the postero-lateral margins of the valve. Fine concentric growth lines are especially prominent along the cardinal margins in front of the row of spines. They commence a short distance in front of the hinge, but become rapidly obsolete on the venter and rarely cross the valve.

Brachial valve is moderately concave, the umbo is depressed below the hinge-line and the postero-lateral margins are flat. Rugae are well defined on the lateral margins and produce a wrinkled appearance across the body of the valve. Costellae are similar to those on the pedicle valve except that occasional bifurcations as well as irregular intercalations take place.

INTERNAL. Pedicle valve. Diductor scars are coarsely striate and are situated in sub-quadrate pits. These are widely separated by longitudinally striate adductor scars. The muscle field is restricted to the posterior portion of the valve and is surrounded by an area of shallow linear pits. The pits grade into impressions of the external ornament towards the anterior margin.

Brachial valve. The median septum is long, well defined, broad posteriorly, tapers anteriorly and extends to the mid-point of the valve. Adductor scars are small, triangular, and occur at the posterior margins of the brachial process. The brachial processes are roughly triangular, longitudinally striate and give rise to poorly defined linear brachial ridges. The cardinal process appears to be quadrilobate externally.

MEASUREMENTS : *Gigantoproductus tenuirugosus* has been described from fragmentary material and consequently cannot be measured accurately. The dimensions of the species can be seen in Plate I.

REMARKS : Because only a small number of poorly preserved specimens are at present available for study the internal morphology of the species is incompletely known. Detailed comparisons are therefore difficult to make.

The closest species appears to be *G. dentifer* (Prentice, 1949, p. 249–257, pl. 11, figs. 2*a–c*, pl. 12, figs. 2*a–b*) which ranges from the C_2S_1 zone to the D_2 zone of Derbyshire, England. *G. tenuirugosus* has a similar shape, but is distinguished by its coarser costate ornament.

The morphologically close specimens of *Productus hemisphaericus* Sowerby described by Davidson (1858, p. 144–145, pl. 40, figs. 4–8) and Delépine (1928, p. 28–29, pl. 4, fig. 53) have been shown by Prentice (1949) to belong to *G. dentifer* ; they are from Warfdale, Yorkshire, England, and the V_{3a} of Belgium, respectively.

Several other forms referred to *Productus hemisphaericus* Sowerby are externally similar to this species and may belong to *Gigantoproductus* ; viz. those described by Krenkel (1913, p. 41–42, pl. 2, fig. 1) from the Utsch-Turfan district of Tian-Shan, and Reed (1927, p. 45, pl. 9, fig. 3) from Ta-shih-wo, Yun-nan.

This species is named from the Latin *tenuis*—slight and *rugosus*—wrinkled, which refer to the small rugae on the lateral margins of the shell.

OCCURRENCE : *Gigantoproductus tenuirugosus* has been collected only from L.235 Dungog.

MATERIAL : F.7122–F.7137. *Holotype* F.7122, *paratypes* F.7123, F.7127B, F.7133.

Family MARGINIFERIDAE Stehli, 1954
Subfamily COSTISPINIFERINAE Muir-Wood and Cooper, 1960
Genus INFLATIA Muir-Wood and Cooper, 1960

TYPE SPECIES : *Productus inflatus* McChesney, 1860.

REMARKS : This material differs from the type species, *Inflatia inflata* (McChesney), in the possession of more narrow adductor muscle scars in the pedicle valve, a shorter hinge, the absence of a fold and sinus and the shorter median septum in the brachial valve. Features

which are comparable with those of the type species are the size, profile, external ornament and the arrangement of spines; the internal morphology of both valves is generally similar in both species.

Inflatia elegans n.sp.

Plate II, figs. 1–18

DIAGNOSIS: Two small spines present along hinge-line of pedicle valve; costae have a density of 13–15 per 10 mm. on anterior portion of trail; sinus absent; greatest width occurs at mid-region of valve; pedicle valve musculature moderately developed. Brachial valve bears prominent geniculation and extensive trail; fold absent; median septum short for the genus, blade-like anteriorly and extends to mid-point of valve.

DESCRIPTION:

EXTERNAL. Pedicle valve is globose, strongly inflated and convex, with the greatest convexity occurring at the umbo and at the commencement of the trail. The visceral disc is gently convex. The umbo is narrow, strongly incurved and extends a short distance behind the hinge-line. Greatest width occurs at the mid-region of the valve. The hinge-line is straight and the postero-lateral margins are flattened but not auriculate. The flanks and the trail are steep and pronounced. In gerontic individuals a flat lip-like extension on the anterior of the trail may extend up to 7 mm. in front of the general trail base and rests against a similar marginal modification of the trail of the brachial valve. Ornament is moderately reticulate and in adult specimens up to 10 rugae occur on the visceral disc. On the anterior portion of the trail the costae have a density of 13–15 per 10 mm. They increase by bifurcation and intercalation. Two small spines are commonly developed on the hinge-line and occasionally two or three additional spines are situated towards the mid-portion of the valve. A median sinus is absent.

Brachial valve is geniculate, has a high concave trail and lateral margin and a shallowly concave visceral disc. On a valve 32 mm. wide and 28 mm. long the trail is 13 mm. high. The greatest concavity occurs at the junction of the trail and the visceral disc and on the posterior shoulders which slope upwards from the depressed visceral region. Gerontic individuals possess a marginal flange on the trail formed by an abrupt geniculation of its anterior-most tip. The pointed umbo is depressed below the level of the hinge. Lateral and postero-lateral regions are flattened, but the extremities are non-auriculate and meet the hinge at right angles. Fourteen to fifteen concentric ribs are present on the visceral disc and the radial ornament has the same density as that on the opposite valve. The brachial valve is aspinose and a median fold is absent.

INTERNAL. Pedicle valve. Diductor scars are triangular in shape, slightly impressed into the shell, commence indistinctly a short distance in front of the umbo and become rapidly broader and flabellate anteriorly. They have irregular but well-differentiated lateral margins. The posterior portions of the diductor scars, the most weakly impressed regions of musculature, are ornamented with fine concentric filae. The remainder of the muscle field is marked by low branching ridges which are sometimes continuous with the internal ornament of the valve. Adductor scars are narrow, elongate, commence a short distance behind the posterior margins and terminate behind the anterior margins of the diductor scars. They are usually elevated above the floor of the valve on narrow platforms, but in some cases are shallowly impressed into the shell. In the first instance they are divided by a median furrow and in the second they are separated by a weak median ridge originating from a small apical callus; the median ridge occurs only in gerontic individuals. Dendritic markings occur on the posterior portions of the adductor scars. Muscle scars are poorly defined in juvenile specimens. A distinct ginglymus extends across the hinge and is divided by the umbonal cavity. The hinge-line is thickened and a weak marginal ridge cuts across the postero-lateral extremities and traverses the trail, in most cases becoming obsolete towards the front of the valve. The internal ornament varies from a densely pitted region adjacent to the muscle field, to an area of parallel longitudinal striations which extends anteriorly from the muscle field and becomes indistinct towards the marginal ridge.

Brachial valve. The adductor scars are differentiated into posterior and anterior pairs. Posterior adductor scars are large, round to ovoid in shape, elevated anteriorly, impressed posteriorly and are strongly dendritic. Anterior adductor scars are lacrimate to rectangular in shape and occur towards the front of, and are partially enclosed by, the divergent posterior pair. They are pointed posteriorly, have well rounded anterior margins and can be either impressed into the shell or, more commonly, be elevated on platforms above the floor of the valve. The anterior adductor scars are smooth, but at least one case of obsolete dendritic

ornament has been observed. The cardinal process is short, bilobate internally, trilobate externally and is buttressed by strong lateral ridges and a median septum. The internal lobes are convex and well rounded, diverge posteriorly and are separated from one another by a deep narrow groove. Externally the lateral lobes are convex, diverge from a smaller peg-like central lobe and are separated from it by a narrow angular furrow. The median septum extends to the mid-point of the valve. It is low, broad and well rounded posteriorly, becomes narrow towards its mid-length and increases in strength towards the anterior extremity, developing into a high blade-like projection. A narrow groove divides the posterior and medial regions of the septum, while the anterior portion is carinate. Brachial ridges arise from the front of the muscle field at the junction of the anterior and posterior adductor scars. They run for a short distance laterally, parallel with the hinge, and then swing anteriorly, enclosing the ovoid to kidney-shaped brachial discs in hook-like curves. Brachial ridges have a variable strength and are usually moderately elevated along their length from the muscle field to the margins of the brachial discs. The ridges are highest on the inner margins of the hooked curves where they surround the elevated discs. In several instances the brachial ridge is not differentiated from the brachial disc, while in some valves, notably juveniles, brachial markings are absent. Brachial discs are smooth or are marked with concentric striae. A smooth region on the floor of the valve extends along the anterior side of the brachial ridges between the brachial discs and the muscle field. The lateral ridges are concave when viewed from the posterior of the valve, rapidly lose strength laterally and fail to reach the lateral margins. A faint groove arises from the lateral margins, extends around the trail and fits into a marginal ridge on the pedicle valve. The groove becomes deep in gerontic forms. The internal ornament is differentiated into three regions ; the first, behind the brachial impressions and on either side of the muscle field, is marked with deep randomly oriented pits ; the second region, between the brachial impressions and the marginal furrow, with radially

MEASUREMENTS (in mm.) :
Pedicle Valve

Specimen Number	Length	Length of Curvature*	Width	Height	Diductor Muscle Field		Adductor Muscle Field	
					Length	Width	Length	Width
F.6941 ..	37	47	38	15	16	25	11	3·5
F.6943 ..	26	43	33·5	13·5	11·5	22	10	3
F.6942 ..	30	53	37	16	15	27	13	6
F.6930 ..	32	45	33	—	—	—	7	3
F.6932 ..	33·5	42	31	11	—	—	7	2·5
F.7004 ..	30	35	35	13	—	—	8	3

Brachial Valve

Specimen Number	Length	Width	Adductor Muscle Field		Length Median Septum	Distance between outer margins of Brachial Ridges
			Length	Width		
F.6982a ..	30	34 est.	7	8	11	20·5
F.6984 ..	27 est.	33 est.	8	10	13	22
F.6985 ..	29	32	6	7	13	22
F.6986 ..	23	25	8	8	14	21
F.6987 ..	27	30	8	9	16	25
F.6988 ..	23	28	—	—	13	—
F.6989 ..	—	31	7·5	8·5	14	23·5
F.6990 ..	24	28·5	6	10	12	20
F.6993 ..	27	24	8	7	15·5	23
F.6995 ..	24	25	5	7	15	21
F.6997 ..	23	28	6	7	12	22
F.6999 ..	25	28	8	7	14	21·5

* The length of curvature is measured from the umbo, around the curvature of the valve, to the mid-point of the anterior margin.

arranged strips of pustules ; and the third, on the trail, with spines which gradually grade into a smooth region anteriorly.

Remarks : Variation within the species is mostly dependent on age. Gerontic individuals become highly globose and inflated, develop a recurved marginal flange on the trails of both valves and have a less distinct external ornament. As expected, juvenile specimens show poor development of muscle scars and brachial markings, but some large specimens also exhibit these features and are distinct from most shells of comparable size. Details of the variation within the musculature of both valves are described above.

The species referred to *Dictyoclostus simplex* by Campbell (1957, p. 57–60, pl. 13, figs. 1–8), from Babbinboon in the Werrie Basin, N.S.W., now appears to belong to *Inflatia*. *I. elegans* is readily distinguished from this species by way of its larger size, more globose shape, longer trail and spinose posterior margin. Internally *I. elegans* is characterized by shorter marginal ridges buttressing the cardinal process, a shorter median septum and better defined brachial markings. The morphology, but not the size, of the adductor muscle scars and brachial markings in the brachial valve is closely comparable in both species. These structures are larger in *I. elegans*.

Inflatia inflata (McChesney), figured by Muir-Wood and Cooper (1960, pl. 55, figs. 1–5), from the Chester Series of Oklahoma, is distinguished from *I. elegans* by its wider hinge-line, stronger adductor scars in the pedicle valve, a longer median septum in the brachial valve and the possession of a fold and sinus.

The specific name is taken from the Latin *elegans*—elegant.

Occurrence : *Inflatia elegans* has been collected from the type locality, L.234 Wiragulla, and from a locality 150 feet stratigraphically above L.235 Dungog.

Material : F.6922–F.7004. *Holotype* F.6985, *paratypes* F.6941–F.6943, F.6956, F.6958, F.6980–F.6982a.

Family ECHINOCONCHIDAE Stehli, 1954
Subfamily ECHINOCONCHINAE Stehli, 1954
Genus ECHINOCONCHUS Weller, 1914

Type species : *Productus punctatus* J. Sowerby, 1882.

Remarks : *Echinoconchus* has been redefined by Muir-Wood and Cooper (1960, p. 243–244), who made the provisional note that the genus is still imperfectly understood. They have retained the *Echinoconchus elegans* and *E. punctatus* groups within the genus, thus supporting Campbell's (1956) contention that there was no basis for their separation as proposed by Chao (1927, p. 53).

A row of hinge spines occurs on the brachial valves in the Dungog material. If these spines were present in other species of the *E. elegans* group they could perhaps clarify the interpretation of the genus. However, a review of the relevant literature, including Grober (1909), Krenkel (1913), Weller (1914), Thomas (1914), Hayasaka (1924), Chao (1927), Delépine (1928), Paeckelmann (1931), Sutton (1938), Muir-Wood (1948) and Sarycheva and Sokolskaya (1952), does not reveal rows of hinge spines to be present on the brachial valves of any other species. The quality of many of the photographs illustrating the above works is poor and should a revision of *E. elegans* group species show such spines then this criterion could be used in the separation of the *E. elegans* and the *E. punctatus* groups.

Echinoconchus gradatus Campbell

Plate V, figs. 6–8

Echinoconchus gradatus Campbell, 1956, J. Paleont., 30, p. 474–476, pl. 49, figs. 14–18.

Echinoconchus gradatus Campbell, 1957, J. Paleont., 31, p. 62.

Remarks : The material from L.235 Dungog differs from the type specimens in only one feature, the possession of one or two rows of spines along or nearly parallel with the hinge-line of the brachial valve. The spines are much larger and longer than those ornamenting the shell, have circular bases, become stronger laterally and curve towards the umbo. One or two spines occur near the junction of each concentric rib with the hinge. The apparent absence of these spines in the type material may be due to the poor preservation of the Babbinboon material.

Occurrence : *Echinoconchus gradatus* is now known from L.35 Babbinboon, the type locality, L.53 Greenhills, L.235 Dungog and the extension of the L.234 Wiragulla horizon, 150 feet stratigraphically above L.235.

Material : F.7022–F.7037.

Suborder SPIRIFEROIDEA Allen, 1940,
emend. Muir-Wood, 1955
Superfamily ROSTROSPIRACEA Schuchert
and Le Vene, 1929
Family ATHYRIDAE Davidson, 1884
Subfamily ATHYRINAE Waagen, 1883
Genus ATHYRIS McCoy, 1884

TYPE SPECIES: *Terebratula concentrica* von Buch, 1834.

REMARKS: This genus has been adequately discussed by a number of authors. Weller (1914, p. 464–465) presented a detailed diagnosis, and a brief summary has been given by Cooper (1944, p. 333). No details of the spires or jugum have been observed in the present material.

Athyris wiragullensis n.sp.
Plate III, figs. 4–10

DIAGNOSIS: Shell globular to sub-elliptical in shape, ornamented by closely spaced concentric lamellae, some of which are produced into regularly spaced outgrowths; these are less well developed on the brachial valve; fold and sinus obsolete, commissure rectimarginate. Pedicle valve interior possesses heart-shaped adductor scars and round to ovoid diductor scars; radial pallial markings prominent. Hinge-plate thickened laterally; brachial adductor scars long, narrow, separated by low myophragm; linear pallial markings well developed.

DESCRIPTION:

EXTERNAL. Pedicle valve is globular to sub-elliptical in outline, has a pronounced and slightly incurved umbo and is most convex at the mid-region of the valve. The lateral shoulders slope evenly to the rounded lateral margins. The hinge-line is curved and the palintropes, when viewed from the posterior of the shell, are barely concave. A faint sinus may occur on the anterior-most portion of the shell, but the commissure is usually rectimarginate. Concentric lamellae are closely spaced and have a density of 20 per 5 mm. towards the anterior margin of the valve. Wider, more prominent lamellae are regularly produced every 3 mm. No details of the foramen have been observed.

Brachial valve is less convex than the pedicle valve, is slightly more elliptical in shape and has a weaker umbo. Lateral shoulders slope evenly to the margins. The fold is obsolete to absent. The ornament is similar to that of the pedicle valve except that the large lamellose flanges are less regularly developed. Fifteen concentric lamellae per 5 mm. have been measured on the anterior of one brachial exterior.

FIG. 6

INTERNAL. Pedicle valve. The pedicle cavity is short, well rounded, tapers posteriorly, becomes deeper anteriorly and in most cases has an undivided floor. Teeth are large, recurved and are supported on stout peg-like dental plates which are confined to the antero-lateral margins of the pedicle cavity. Transverse striations ornament the region behind the teeth, the anterior portion of the pedicle cavity and the inner margins of the dental lamellae. Adductor scars occur as a heart-shaped impression in front of the pedicle cavity and between the posterior of the diductor scars. They are most strongly impressed posteriorly and are divided by a median line which expands anteriorly into a narrow ridge and extends to the front of the diductor muscle field. Diductor scars are round to sub-ovoid, poorly impressed, have well rounded posterior margins and less well defined, broadly rounded anterior extremities. Faint linear vascula genitalia arise from the muscle field and project radially towards the margins of the valve (Text-fig. 6). In addition, an obsolete radial system of vascular markings has been observed around the margins of most pedicle valves. A small number of genital pits occurs in the postero-lateral regions of the valve.

Brachial valve. The hinge-plate has a round apical perforation and extensively thickened lateral margins which form the inner supports of the sockets and are also produced anteriorly to form crurae. Sockets are deeply impressed, divergent, are narrow towards the umbo, broaden antero-laterally and, with the exception

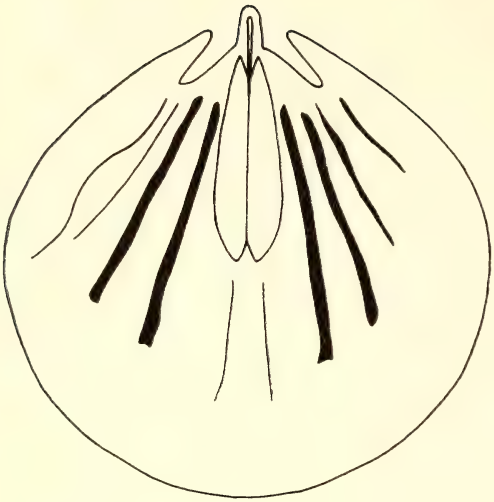

FIG. 7

of one longitudinal groove, have a rounded floor. Adductor scars are narrow, elongate and have well impressed and pointed posterior extremities. They expand medially, taper anteriorly, have rounded anterior margins and are divided by a narrow myophragm extending to the front of the muscle field. The myophragm commences from beneath the hinge-plate, is relatively strong posteriorly and weakens anteriorly. Two well defined pairs of divergent vascular trunks originate towards the postero-lateral margins of the adductor scars (Text-fig. 7). Faint vascular markings are present around the margins of the valve. One specimen exhibits an evenly crenulate furrow which, except for a divergence at one side, runs parallel with the growth lines. The regularity and the position of the furrow suggests that it was formed by the mantle, but its precise function is unknown (see Text-fig. 8).

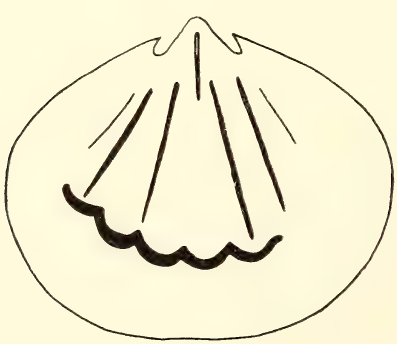

FIG. 8

MEASUREMENTS (in mm.) :
Pedicle Valve

Specimen Number	Length	Width	Muscle Field	
			Length	Width (median)
F.7006 ..	23	27	8·5	11
F.7007 ..	21	23·5	7·5	9
F.7008 ..	21	26	—	—
F.7015 ..	24	30 est.	10	14
F.6982b ..	16·5	20	6·5	8

Brachial Valve

Specimen Number	Length	Width	Muscle Field	
			Length	Width (median)
F.7005 ..	32	35	17	5·5
F.7009 ..	20	24	—	—
F.7010 ..	20·5	21·5	10	2
F.7011 ..	22	25	—	—
F.7012 ..	20·5	23	10·5	4

REMARKS : The globose shape and almost total obsolescence of the fold and sinus distinguishes *Athyris wiragullensis* from most overseas Carboniferous *Athyris* species.

Certain specimens of *Athyris planosulcata* (Phillips) from Bolland, Derbyshire, England, described by Davidson (1857, p. 80, pl. 16, figs. 4, 5, 12) resemble this species in shape, style of ornament and the lack of a prominent fold and sinus. However, because the internal morphology of *A. planosulcata* is unknown a detailed comparison cannot be made.

A. membranacea de Koninck (1887, p. 89–90, pl. 19, figs. 1–4) has a similar ornament and profile to *A. wiragullensis,* but is distinguished by the possession of a uniplicate commissure and a marked sinus in the pedicle valve. The internal details of the Belgian species are unknown. *A. membranacea* occurs in the T_1 of Tournai, Belgium.

This species is named after the small railway siding, Wiragulla, situated a short distance from the L.234 locality.

OCCURRENCE : *Athyris wiragullensis* is known from the type locality, L.234 Wiragulla, and the extension of this horizon 150 feet stratigraphically above L.235 Dungog.

MATERIAL : F.7005–F.7015, F.6982b. *Holotype* F.7005, *paratypes* F.7006, F.7008.

Superfamily SPIRIFERACEA Waagen, 1883
Family SPIRIFERIDAE King, 1846
Subfamily SPIRIFERINAE King, 1846
Genus SPIRIFER Sowerby, 1816

TYPE SPECIES : *Conchyliolithus Anomites striatus* Martin, 1793 (by suspension of the rules of the International Commission on Zoological Nomenclature).

Spirifer osbornei n.sp.

Plate III, figs. 11–15 ; Plate IV, figs. 1–11

DIAGNOSIS : Shell wider than long ; commissure weakly uniplicate ; ornament of 60–80 costae crossed by concentric growth lamellae. Radial micro-ornament completely obsolete. Pedicle valve strongly convex with high concave cardinal area ; adminicula are well developed in juveniles but are obscured by a posterior thickening in mature specimens ; the callus almost entirely fills the delthyrium ; the muscle field is sharply pointed in juveniles aad becomes large, sub-quadrate and impressed in later stages of growth. Brachial valve less convex with low inclined cardinal area ; distinct posterior and anterior adductor scars present in mature forms.

DESCRIPTION :

EXTERNAL. The shell is large, unequally biconvex, wider than long and triangular in shape. The greatest width occurs at the hinge-line or between the hinge and the mid-length of the shell. Cardinal extremities appear to be mucronate in juvenile growth stages but become pointed or bluntly rounded in adults. The commissure is weakly uniplicate. Costae are broadly rounded, widen anteriorly and are twice as wide as the separating sulci. The costae increase by bifurcation. On a shell 44 mm. wide and 30 mm. long there are from 60–80 costae around the commissure, their density being 10 per 10 mm. on the median anterior portion of the shell. Concentric growth lamellae are particularly well developed on the lateral extremities. No radial micro-ornament has been observed on well preserved shells.

Pedicle valve is most strongly convex around the umbo, which is incurved over the apex of the delthyrium. The slightly concave lateral shoulders slope steeply to the flattened postero-lateral margins. In older individuals the front of the valve becomes flattened and may form a trough-like flange, especially at the median sinus. The sinus originates at the umbo, where it is shallow and sub-quadrate in section, becomes broader and more rounded anteriorly and is extended into a shallow lingual extension at the front of the valve. In some cases it is weakly developed or almost absent. The cardinal area is high, most concave immediately beneath the umbo and is ornamented with horizontal growth striations. The delthyrium is narrow, triangular and extends to the tip of the umbo ; the delthyrial angle ranges between 40° and 50°. The pattern of sinal costation has not been observed.

Brachial valve is less convex than the pedicle valve. The umbo barely overhangs the hinge and the most convex region occurs at the mid-point of the valve. Lateral shoulders slope gently from the fold to the flattened postero-lateral margins. The fold is low, broadly rounded, commences at the umbo and extends to the anterior margin. A low inclined cardinal area occurs along the hinge-line.

INTERNAL. Pedicle valve. The muscle field is rectangular to elliptical in shape, deeply impressed posteriorly and is level with the floor of the valve anteriorly. Diductor scars are pointed or rounded at both ends and are ornamented with parallel longitudinal striations or with a prominent radiating dendritic pattern originating from a point at their mid-length. The lateral portions of the diductor scars are sometimes elevated above the remainder of the muscle field. Adductor scars are narrow, linear, occur between the diductor scars and are separated by a low myophragm. In some instances they expand into a broader platform on the mid-region of the muscle field. Traces of the curving adminicula occur around the postero-lateral margins of the muscle field. The dental lamellae are almost obscured by the heavy thickening on the umbonal region of the valve, run down the sides of the delthyrium and support strong divergent teeth at their extremities. A callus fills the apex of the delthyrium. An area of genital pits occurs adjacent to the muscle field and extends down the cardinal area. Vascula genitalia trunks are narrow, linear, radially directed and branch from the pitted area. A narrow trunk of vascula media arises from the base of the muscle field and runs towards the anterior margin.

Brachial valve. Two pairs of adductor scars are situated on the posterior portion of the fold and extend to the mid-point of the valve. Both pairs are divided by a sharp myophragm which arises a short distance in front of the umbo and runs to the termination of the muscle field. Posterior adductor scars are smooth, have a divided sub-circular shape, are rounded posteriorly and sharply pointed anteriorly. Two pallial trunks branch from the front of the

posterior adductor scars. The anterior adductor scars are elongate, taper posteriorly, have wider, broadly rounded or straight anterior extremities and are slightly impressed into the shell. They are marked with a dendritic or striate pattern. Sockets are divergent, taper posteriorly and broaden anteriorly. Crural plates are wedge-shaped, support the inner margins of the sockets and extend into the umbo on either side of the cardinal process. In older individuals they reach the floor of the valve. The cardinal process is composed of 25–30 thin vertical lamellar plates arranged in a V-shaped pattern. Faint genital pits are present on the postero-lateral shoulders. From each region extremely narrow branching vascula genitalia trunks run to the lateral margins of the valve.

Variation within the species :

Pedicle valve. Variation occurring throughout the morphogeny of the species is shown by changes in the apical thickening, adminicula and the muscle field. In juveniles the muscle field is narrow, elongate, sharply pointed posteriorly, tapers anteriorly and is surrounded posteriorly by strong adminicula. No apical thickening is present. With increasing age the valve thickens along the hinge, especially at the umbo, and shell material encloses the dental lamellae and posterior portions of the adminicula. The muscle field becomes broader and more impressed, but still remains markedly elongate and pointed posteriorly. Mature forms, such as described above, show only traces of the adminicula on the postero-lateral margins of the muscle field because of the increased apical thickening and have larger and more deeply impressed muscle scars. Gerontic individuals are massively thickened posteriorly, show no traces of adminicula and have a somewhat less impressed, but larger sub-quadrate muscle field.

Brachial valve. Young specimens possess undifferentiated adductor scars in the form of the elongate sub-rectangular anterior pair. Mature individuals, as described above, have two clearly defined pairs of muscle scars. Crural plates are small in juveniles but become stronger in older specimens and extend to the floor of the valve on either side of the cardinal process.

Remarks : The pattern of sinal costae has not been observed because of the poor preservation of the external moulds.

Spirifer osbornei is in many ways comparable with *S. lirellus* Cvancara (1958, p. 873–876, pl. 112, figs. 1–7, 11) from Barrington, N.S.W. It is distinguished from *S. lirellus* by the possession of a more massively thickened pedicle valve, a micro-ornament of concentric growth lines but apparently no radial lirae, a coarser costate ornament, a less pronounced umbo on the brachial valve and a weaker median sinus on the pedicle valve.

Measurements (in mm.) :

Pedicle Valve

Specimen Number	Length	Width	Muscle Field	
			Length	Width
F.7038 ..	38	43	18	11
F.7039 ..	30	41	15	8
F.7040 ..	42	48 est.	16	10
F.7041 ..	30	42	16·5	11
F.7042 ..	—	43	14	10
F.7043 ..	—	52	22	18
F.7062 ..	45	59	—	—

Brachial Valve

Specimen Number	Length	Width	Muscle Field	
			Length	Width
F.7049 ..	38	46	15	8
F.7050 ..	29	44	—	—
F.7056 ..	25	36	10	4
F.7058 ..	35	48	16·5	9

The external ornament of *S. osbornei* resembles that of *S. suavis* de Koninck, described by Vaughan (1915, p. 42, pl. 6, fig. 7), from the T_{2b} (Upper Tournaisian) of Belgium. However, because the internal details of the Belgian species are unknown a closer comparison cannot be made. The material used in the original description of *S. suavis* de Koninck (1887, p. 118, pl. 27, figs. 28–33) is distinguished from this species by its more pronounced fold and sinus, the stronger nature of the uniplicate commissure and its greater convexity. Demanet (1958) has recorded *S. suavis* from the Tn_{2a}, Tn_{2c}, Tn_{3b} and Tn_{3c} of Belgium.

Spirifer logani Hall, described by Weller (1914, p. 363–364, pl. 56, figs. 1–3 ; pl. 57, figs. 1–3) from the Keokuk Limestone, Mississippi Valley, U.S.A., is much larger, has a more convex brachial valve, a more pronounced fold and sinus, a lower pedicle valve with a less incurved umbo, is less thickened at the apex of the pedicle valve and has a wider delthyrium.

Spirifer cf. *S. liangchowensis* Chao, described by Maxwell (1954, p. 48–49, pl. 6, figs. 7–10)

from the Neil's Creek Clastics, Mt. Morgan, Queensland, is comparable in internal details with *S. osbornei*. These similarities include the morphology of the adminicula and muscle field in the pedicle valve (in specimens of adult age of *S. osbornei*) ,and the median ridge in the brachial valve. However, *S.* cf. *S. liangchowensis* is distinguished by its more convex brachial valve, curved area on the pedicle valve and the possession of coarser flattened costae which increase by bifurcation and intercalation and are separated by narrow intercostal grooves.

Spirifer aff. *S. liangchowensis* Chao, described by Yanagida (1962, p. 96–98) from Akiyoshi, Japan, is distinguished by its coarser costae, which bifurcate up to three times along their length, and extremely slender adminicula. No mention of the morphogenetic variation in shell thickness has been made, but Yanagida noted that the apical portions of the pedicle valve are extremely thickened. The brachial valve of the Japanese form has not been described.

Spirifer liangchowensis Chao (1929, p. 6–9, pl. 1, figs. 1–7) is distinguished by its greater convexity and incipient fasciculate external ornament.

This species is named after the late G. D. Osborne, one of the early geological workers in the Hunter Valley, N.S.W.

OCCURRENCE: *Spirifer osbornei* is known from L.234 Wiragulla, the type locality, and the extension of this horizon, 150 feet stratigraphically above L.235 Dungog.

MATERIAL: F.7038–F.7082, F.7020b. *Holotype* F.7038, *paratypes* F.7020b, F.7041, F.7043, F.7044, F.7047, F.7049, F.7062, F.7070.

Subfamily PHRICODOTHYRINAE Caster, 1939

Genus KITAKAMITHYRIS Minato, 1951

TYPE SPECIES: *Kitakamithyris tyoanjiensis* (Minato), 1951.

REMARKS: This genus has been adequately discussed by Maxwell (1961) and Roberts (1965).

Kitakamithyris sp.

Plate III, figs. 1–3

DESCRIPTION:

EXTERNAL. The shell is sub-elliptical in shape, equally biconvex and has well rounded cardinal margins. It is ornamented with concentric lamellae bearing coarse biramous spine bases which have a density of 5 per 5 mm. at the anterior margin of the shell. There are approximately 8 concentric lamellae per 10 mm. on the same region of the shell. The lamellae are marked with concentric growth lines.

Pedicle valve is wider than long and is most convex at the tip of the incurved umbo. Lateral shoulders slope evenly from the apex. The median sinus is completely obsolete. No details of the delthyrium have been observed.

Brachial valve has almost the same convexity as the pedicle valve. The umbo is blunt and barely incurved over the cardinal area. The region of greatest convexity occurs immediately in front of the umbo. Lateral slopes are flatter than on the pedicle valve and the fold is almost entirely obsolete.

INTERNAL. Pedicle valve. The muscle field is divided by a prominent median septum extending almost half the length of the valve. The septum is triangular in cross section, highest near the umbo and becomes broader and lower anteriorly. Elongate adductor scars are situated on the steep sides of the median septum. Diductor scars are pointed posteriorly, expand anteriorly as far as the tips of the adminicula and then curve rapidly inwards, terminating at the tip of the median septum. They are slightly impressed into the shell and are marked by regular or wavy longitudinal striations. Adminicula extend three-quarters the length of the median septum, or one-third the length of the valve, and diverge at 25° to 30°. Internal

MEASUREMENTS (in mm.):
Pedicle Valve

Specimen Number	Length	Width	Muscle Field		Length Median Septum	Angle of divergence of Dental Lamellae
			Length	Width		
F.7017 ..	30	36	13	8	15·5	25°
F.7016 ..	20	30	13	7	13	30°

Brachial valves are fragmentary and cannot be measured.

ornament consists of longitudinal striae having a density of 10 per 5 mm. at the anterior margin. In addition, an area of irregular crenulations and incipient genital pits occurs adjacent to the muscle field.

Brachial valve. Adductor scars are elongate and narrow for their entire length and extend approximately two-thirds the length of the valve. A low knife-like myophragm arises from a small callus situated a short distance in front of the umbo and extends to the anterior margin of the muscle field. Sockets are shallow divergent depressions and are supported on their inner margins by large crural plates. The crural plates buttress the sides of the cardinal process and on some specimens reach the floor of the valve. The V-shaped cardinal process is composed of approximately 20 thin vertical lamellar plates. Internal ornament consists of fine radiating striae.

REMARKS: Too few specimens are available to warrant the designation of a new specific name. However, this material is readily distinguishable from all previously described eastern Australian *Kitakamithyris* species.

K. rouchelensis (Campbell) (1955, p. 380–381, pl. 18, figs. 16–17) from Rouchel Brook, N.S.W., has a similar shape and ornament, but is distinguished by the possession of shorter adminicula and a longer median septum in the pedicle valve and the presence of a fold and sinus on the exterior of the shell.

K. uniplicata (Campbell) (1955, p. 377–379, pl. 18, figs. 1–9) is characterized by a more transverse shape, the presence of a fold and sinus and has a greater number of lamellae and spines ornamenting the shell. In the interior of the pedicle valve the median septum and adminicula are less equal in length. *K. uniplicata* has been collected from L.35 Babbinboon, L.233 Trevallyn, L.53 Greenhills and Glen William, Clarencetown.

K. triseptata (Campbell) (1955, p. 379–380, pl. 18, figs. 10–15) from Babbinboon, Trevallyn and Greenhills, has shorter, more widely divergent adminicula and a longer median septum in the pedicle valve, a shorter myophragm in the brachial valve and a greater density of spine bases on the external ornament.

K. campbelli (Cvancara) (1958, p. 870–872, pl. 111, figs. 14–20, 23, 25) from Barrington, N.S.W., has a weak fold and sinus, a slightly denser spinose ornament, a longer median septum in the pedicle valve and sub-parallel sockets in the brachial valve.

K. globosa Maxwell (1961, p. 101, pl. 20, figs. 25–26) from Old Cannindah, Queensland, is distinguished by its more globular shape, more closely spaced concentric lamellae and greater biconvexity.

OCCURRENCE: *Kitakamithyris* sp. is known only from L.234 Wiragulla.

MATERIAL: F.7017–F.7021.

Suborder TEREBRATULOIDEA Muir-Wood, 1955

Superfamily TEREBRATULACEA Waagen, 1883

Family DIELASMATIDAE Schuchert and Le Vene, 1929

Genus BALANOCONCHA Campbell, 1957

TYPE SPECIES: *Balanoconcha elliptica* Campbell, 1957.

REMARKS: Campbell distinguished *Balanoconcha* from *Dielasma* King by the absence of dental lamellae. He remarked in a footnote (p. 86) that work by Stehli (1956) had confirmed this distinction.

Balanoconcha elliptica Campbell

Plate V, figs. 12–18

Balanoconcha elliptica Campbell, 1957, J. Paleont., 31, p. 86–88, pl. 15, figs. 13–15.

REMARKS: Except for the absence of a median ridge in some pedicle interiors and a slight difference in the distribution and density of the punctae, the L.235 Dungog specimens are identical with the type material.

Punctae are less dense in this material, approximately 300 punctae occurring per square mm. on the median portion of the shell compared with 400–450 per square mm. on the same region of the type material. The punctae are always oriented in regular wavy concentric rows compared with their usual irregular orientation in the Babbinboon specimens. Campbell noted that only some areas in the type material exhibited a regular linear arrangement of punctae.

Pallial markings are more strongly defined in the brachial valve, but this feature may vary with differing preservations.

Sockets are divergent, well rounded, pointed posteriorly, broaden antero-laterally and are supported on their inner margins by strong socket ridges. These were not previously described.

OCCURRENCE: *Balanoconcha elliptica* is known from L.35 Babbinboon, the type locality, L.235

Dungog and an extension of L.234 Wiragulla 150 feet stratigraphically above L.235.

MATERIAL : F.7083–F.7095, F.7138.

Pelecypoda

Subfamily STREBLOCHONDRINAE Newell, 1937

Genus STREBLOPTERIA McCoy, 1851

TYPE SPECIES : *Streblopteria laevigata* (McCoy).

REMARKS : Newell (1937, p. 87–88) presented a definition of the genus and attempted to unravel McCoy's original description. The genus at present remains in a confused state and the author is unable, through lack of suitable material, to add further to Newell's remarks.

Three features of this material are not in exact accordance with Newell's diagnosis. Firstly, the anterior auricle is longer than the posterior auricle ; secondly, the anterior auricular sulcus on the left valve is not especially prominent ; and thirdly, the valves are slightly less gibbous than those of the type species. In spite of these differences, reference to *Streblopteria* is supported by the lack of body ornament, the morphology of the posterior auricle and the shape of the shell.

Streblopteria sp.

Plate V, figs. 9–11

DESCRIPTION :

EXTERNAL. The shell is smooth, acline and has valves of almost equal convexity. The hinge-line is approximately half as long as the shell. A moderately defined anterior umbonal fold contrasts with the weak posterior umbonal fold. The umbo is pointed and projects a short distance over the hinge-line. The posterior auricle is a continuation of the shell margin, is well differentiated from the body of the shell on the right valve, but is less well defined on the left valve. It joins the hinge at an angle of approximately 120° and is half as long as the anterior auricle. The anterior auricle is well defined and has a rounded extremity. On the right valve it is convex, separated from the umbonal shoulder by a deep narrow groove and is ornamented with strongly defined radiating costae crossed by regularly spaced concentric ribs. The byssal notch is marked by closely spaced growth lines. On the left valve the anterior auricle is flattened and lies well below the level of the umbonal fold.

INTERNAL details are very poorly preserved, but one specimen exhibits a ridge-like thickening along the inner margin of the posterior auricle.

MEASUREMENTS (in mm.) :

Specimen Number		Length	Height	Hinge Length
F.7119	Right valve ..	21	—	11
F.7120	Left valve ..	25	24·5	12

REMARKS : Little can be said on the affinities of *Streblopteria* sp. because of the poor preservation of the available material. This species may be similar to the specimen from near Gresford referred to *Aviculopecten ptychotis* McCoy by Etheridge and Dun (1906, pl. 15, fig. 7), but the absence of an adequate description of this form renders a more detailed comparison impossible. Etheridge and Dun's reference of the Gresford specimen to *A. ptychotis* McCoy is most likely invalid. Newell (1937, p. 115) questionably referred the latter specimen to the genus *Streblochondria*.

OCCURRENCE : *Streblopteria* sp. has been collected from L.235 Dungog.

MATERIAL : F.7118–F.7121.

Family AVICULOPECTINIDAE Etheridge Jr., 1906 emend. Newell, 1937

Subfamily AVICULOPECTININAE Meek and Hayden, 1846 emend. Newell, 1937

Genus AVICULOPECTEN McCoy, 1851 emend. Newell, 1937

TYPE SPECIES : *Aviculopecten planoradiatus* McCoy, 1851, by subsequent designation by Hind (1903).

REMARKS : A detailed account of the morphology and affinities of the genus have been presented by Newell (1937, p. 43–46).

Aviculopecten sp.

Plate V, figs. 1–5

DESCRIPTION :

Left valve is small, acline, higher than long, sub-rectangular in shape and moderately convex. The umbo is narrow, well rounded and projects a short distance over the hinge-line. The hinge-line is straight and approximately two-thirds the length of the shell. A well defined auricular sulcus separates the anterior auricle from the prominent anterior umbonal fold. The auricles are sub-equal. The anterior auricle is triangular, broadly convex and has a rounded anterior extremity. The posterior auricle is weakly differentiated from the posterior umbonal fold and becomes flattened posteriorly. In some cases the postero-dorsal margin of the posterior

auricle appears to be extended into a slight projection, but it usually runs at right angles to the hinge. The external ornament consists of narrow rounded costae distributed in three orders. The costae increase by regular intercalation and there are from 40–48 costae of all orders present on the body of a mature valve. They are crossed by regular closely spaced concentric growth lamellae which are particularly prominent on the anterior auricle. The anterior and posterior auricles are both ornamented with six well defined costae. Internal details of the valve are obscured by the impression of the external ornament.

MEASUREMENTS (in mm.):
Left valve

Specimen Number	Length	Height	Length of Hinge
F.7109a	13	14	—
F.7110	18	16	10
F.7112	14	16	—
F.7116	16	15	9 est.

REMARKS: *Aviculopecten lyelli* Dawson, figured by Bell (1929, pl. 27, figs. 9–15, pl. 28, figs. 1–3), has a comparable shape and style of ornament to that of *Aviculopecten* sp. The Australian species is distinguished by its smaller size and smaller and more convex anterior auricle on the left valve. *A. lyelli* occurs in the Lower Windsor Series (Upper Mississippian) of the Horton-Windsor district, Nova Scotia.

The poor preservation of the Dungog specimens and the lack of right valves prevents the making of further comparisons.

OCCURRENCE: *Aviculopecten* sp. has been collected from L.235 Dungog and an extension of the L.234 Wiragulla horizon, 150 feet stratigraphically above L.235.

MATERIAL: F.7109–F.7117.

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Explanation of Plates

Plate I

Figs. 1–10. *Chonetes cangonensis* n.sp.

1*a*. ×4. F.7097. External mould of pedicle valve; paratype.
1*b*. ×4. F.7097. Rubber cast of pedicle valve exterior; paratype.
2*a*. ×4. F.7096b. Rubber cast of pedicle valve exterior; paratype.
2*b*. ×4. F.7096b. External mould of pedicle valve; paratype.
3. ×4. F.7107a. External mould of brachial valve.
4. ×4. F.7107b. Internal mould of pedicle valve.
5. ×4. F.7102. Internal mould of pedicle valve; paratype.
6. ×4. F.7107c. Internal mould of pedicle valve.
7. ×4. F.7098a. Rubber cast of brachial exterior.
8. ×4. F.7096c. Internal mould of brachial valve.
9. ×4. F.7098b. Internal mould of brachial valve.
10*a*. ×4. F.7096a. Rubber cast of brachial valve interior; holotype.
10*b*. ×4. F.7096a. Internal mould of brachial valve; holotype.

Figs. 11–19. *Gigantoproductus tenuirugosus* n.sp.

11. ×2. F.7135. External mould of brachial valve.
12. ×2. F.7134. External mould of brachial valve.
13. ×1·5. F.7136. External mould of brachial valve.
14. ×1. F.7127b. Rubber cast of pedicle valve exterior; paratype.
15. ×1. F.7122. Rubber cast of pedicle valve exterior showing the row of hinge spines; holotype.
16. ×1. F.7137. Internal mould of pedicle valve; some shell material still remains.
17. ×1. F.7123b. Internal mould of pedicle valve; some shell material still remains.
18. ×1. F.7127c. Rubber cast of pedicle valve exterior showing the costellate ornament.
19. ×1. F.7132a. Rubber cast of brachial valve interior; paratype.

Plate II

Figs. 1–18. *Inflatia elegans* n.sp.

1*a*.	×1.	F.6984.	Rubber cast of brachial valve interior.
1*b*.	×1.	F.6984.	Internal mould of brachial valve.
2*a*.	×1.	F.6985.	Rubber cast of brachial valve interior ; holotype.
2*b*.	×1.	F.6985.	Internal mould of brachial valve ; holotype.
3*a*.	×1.	F.6989.	Rubber cast of brachial valve interior ; paratype.
3*b*.	×1.	F.6989.	Internal mould of brachial valve ; paratype.
4.	×1.	F.6986.	Rubber cast of brachial valve interior.
5.	×1.	F.6999.	Internal mould of brachial valve.
6.	×1.	F.6987.	Rubber cast of brachial valve interior.
7.	×1.	F.6982*a*.	Rubber cast of brachial valve interior showing long trail ; paratype.
8.	×6.	F.6960.	Rubber cast of the external face of the cardinal process.
9.	×1.	F.6955.	Rubber cast of pedicle valve exterior.
10.	×1.	F.6959.	Rubber cast of pedicle valve exterior ; note the spines along the hinge.
11.	×1.	F.6957*a*, *b*.	Rubber cast of two young pedicle exteriors.
12.	×1.	F.6978.	External mould of brachial valve.
13.	×1.	F.6977.	External mould of brachial valve.
14.	×1.	F.6981.	External mould of brachial valve ; note the flange on the anterior margin of the trail ; paratype.
15.	×1.	F.6980.	Rubber cast of brachial valve exterior ; paratype.
16*a*.	×1.	F.6943.	Internal mould of pedicle valve viewed from the side ; paratype.
16*b*.	×1.	F.6943.	Internal mould of same valve.
17.	×1.	F.6956.	Rubber cast of pedicle valve exterior ; paratype.
18.	×1.	F.6941.	Internal mould of pedicle valve.

Plate III

Figs. 1–3. *Kitakamithyris* sp.

1.	×1.	F.7017.	Internal mould of pedicle valve.
2.	×1·5.	F.7016.	Internal mould of pedicle valve.
3.	×1·5.	F.7018.	Internal mould of brachial valve.

Figs. 4–10. *Athyris wiragullensis* n.sp.

4*a*.	×1·5.	F.7007.	Internal mould of pedicle valve ; paratype.
4*b*.	×1·5.	F.7007.	Rubber cast of pedicle valve exterior ; paratype.
5*a*.	×2.	F.6982*b*.	Internal mould of pedicle valve.
5*b*.	×2.	F.6982*b*.	Rubber cast of brachial valve exterior.
6.	×1·5.	F.7006.	Internal mould of pedicle valve ; paratype.
7.	×1·5.	F.7010.	Internal mould of brachial valve.
8.	×1·5.	F.7009.	Internal mould of brachial valve ; note the crenulate pallial mark.
9.	×1.	F.7005.	Internal mould of brachial valve ; holotype ; note the linear pallial trunks.
10.	×1·5.	F.7012.	Internal mould of brachial valve.

Figs. 11–15. *Spirifer osbornei* n.sp.

11.	×1.	F.7071*a*.	Rubber cast of cardinal regions of both valves.
12.	×1.	F.7069.	Rubber cast of pedicle valve exterior.
13.	×1.	F.7062.	Rubber cast of pedicle valve exterior ; old specimen ; paratype.
14.	×1.	F.7070.	Rubber cast of brachial valve exterior ; paratype.
15.	×1.	F.7041.	Rubber cast of pedicle valve exterior ; paratype.

Plate IV

Figs. 1–11. *Spirifer osbornei* n.sp.

1.	×1.	F.7056.	Internal mould of brachial valve.
2.	×1.	F.7049.	Internal mould of brachial valve ; older specimen showing two pairs of adductor scars ; paratype.
3.	×2.	F.7020*b*.	Internal mould of juvenile pedicle valve ; note the well-defined dental lamellae and pointed muscle field ; paratype.
4.	×2.	F.7048.	Internal mould of juvenile pedicle valve.
5*a*.	×1.	F.7041.	Internal mould of slightly older pedicle valve showing the pointed muscle field and slightly shorter dental lamellae ; paratype.
5*b*.	×1.	F.7041.	Rubber cast of same pedicle interior ; paratype.
6.	×1.	F.7039.	Internal mould of pedicle valve.
7.	×1.	F.7042.	Internal mould of pedicle valve ; this specimen is older than both numbers 5 and 6, has a more bluntly shaped muscle field and shorter dental lamellae.
8*a*.	×1.	F.7040.	Internal mould of mature pedicle valve ; note the deeply impressed muscle field and the absence of dental lamellae.
8*b*.	×1.	F.7040.	Rubber cast of the same pedicle valve.
9*a*.	×1.	F.7038.	Internal mould of mature pedicle valve showing well-defined pallial trunks and deeply impressed muscle field ; holotype.
9*b*.	×1.	F.7038.	Rubber cast of the same valve ; holotype.
10*a*.	×1.	F.7043.	Internal mould of older pedicle valve showing very broad muscle field ; paratype.
10*b*.	×1.	F.7043.	Rubber cast of same pedicle valve ; note the extensive apical thickening ; paratype.
11.	×1.	F.7044.	Internal mould of pedicle valve of old or gerontic specimen ; note the thickened apical region ; paratype.

Plate V

Figs. 1–5. *Aviculopecten* sp.

1.	×2.	F.7110.	Internal mould of left valve.
2.	×2.	F.7116.	Internal mould of left valve.
3*a*.	×2.	F.7109*a*.	Internal mould of left valve.
3*b*.	×2.	F.7109*a*.	Rubber cast of exterior of left valve.
4.	×2.	F.7109*b*.	Internal mould of left valve.
5.	×2.	F.7114.	Internal mould of left valve.

Figs. 6–8. *Echinoconchus gradatus* Campbell.

6*a*.	×2.	F.7022.	External mould of brachial valve.
6*b*.	×2.	F.7022.	Rubber cast of exterior of brachial valve ; note the rows of spines near the hinge.
6*c*.	×2.	F.7022.	Rubber cast of brachial valve interior.
6*d*.	×2.	F.7022.	Internal mould of brachial valve.
7.	×2.	F.7028.	External mould of brachial valve.
8*a*.	×2.	F.7035.	Rubber cast of pedicle valve exterior.
8*b*.	×2.	F.7035.	Internal mould of pedicle valve.

Figs. 9–11. *Streblopteria* sp.

9.	×1·5.	F.7118.	Internal mould of left valve.
10*a*.	×1·5.	F.7119.	Rubber cast of exterior of right valve.
10*b*.	×1·5.	F.7119.	Internal mould of right valve.
11.	×1·5.	F.7120.	Rubber cast of left valve.

Figs. 12–18. *Balanoconcha elliptica* Campbell.

12.	×2.	F.7138.	Exterior of pedicle valve.
13.	×2.	F.7083.	Internal mould of pedicle valve.
14.	×2.	F.7089*a*.	Internal mould of pedicle valve.
15.	×2.	F.7089*b*.	Rubber cast of brachial valve exterior.
16.	×2.	F.7084.	Internal mould of brachial valve ; note the well developed pallial trunks.
17.	×2.	F.7083.	Internal mould of brachial valve.
18.	×2.	F.7085.	Internal mould of brachial valve.

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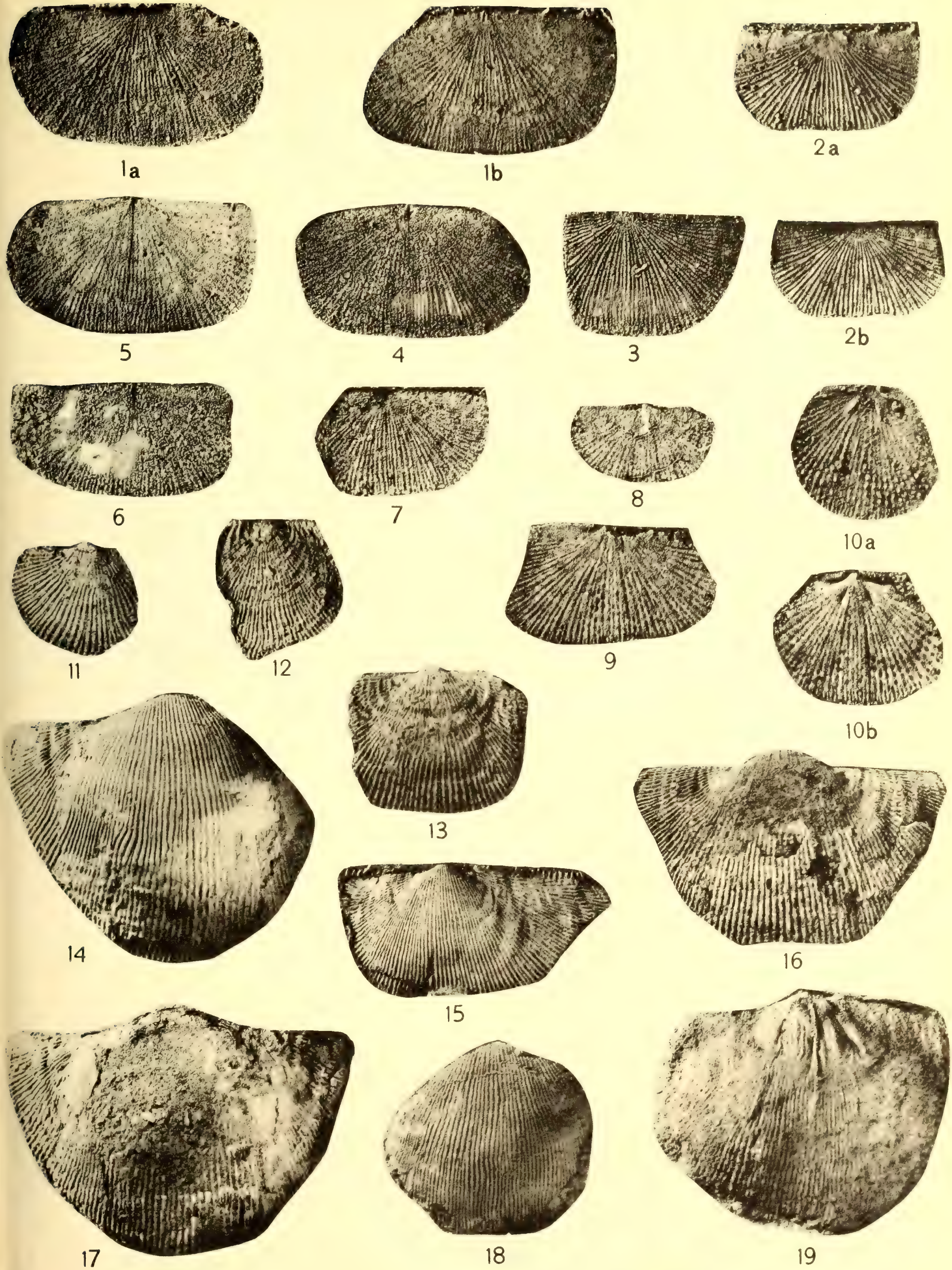
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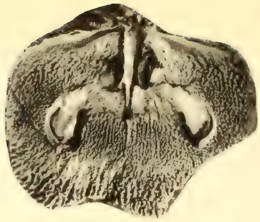
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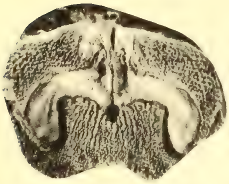
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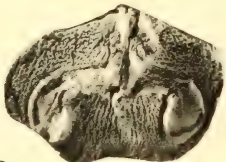
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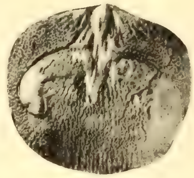
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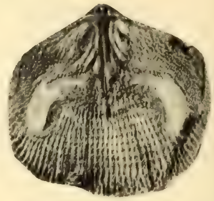
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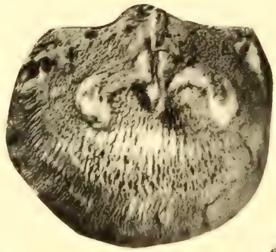
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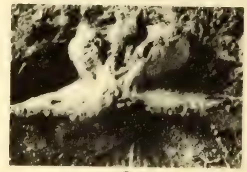
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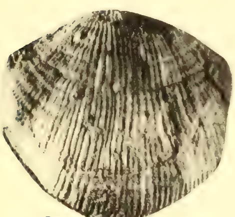
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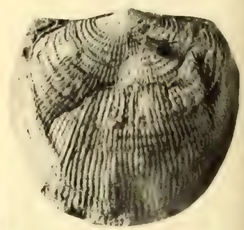
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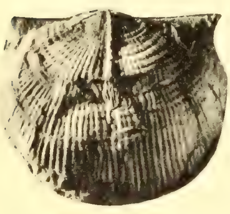
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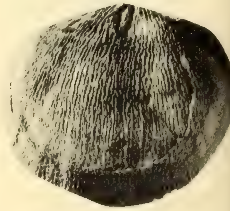
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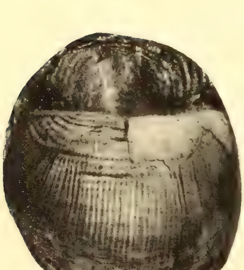
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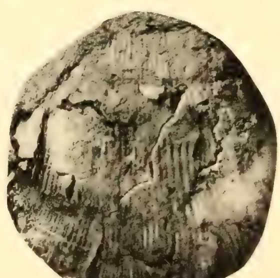
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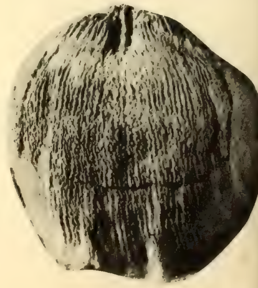
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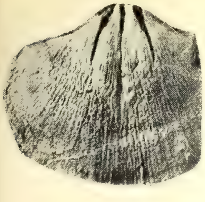
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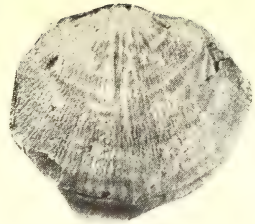
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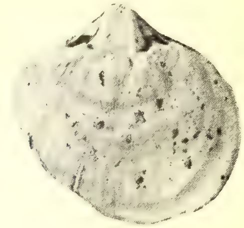
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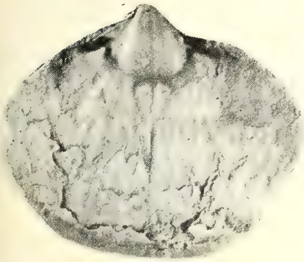
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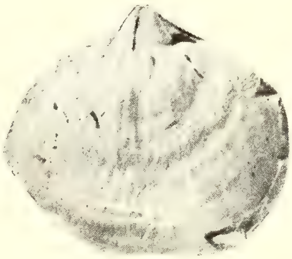
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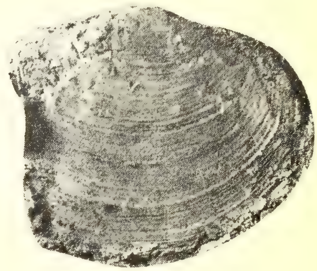
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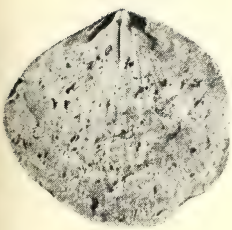
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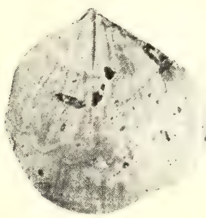
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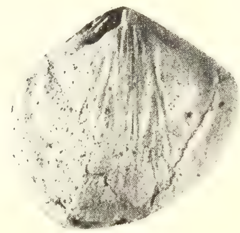
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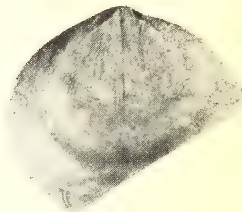
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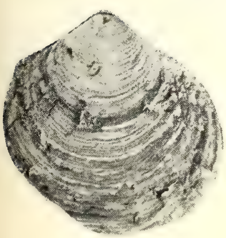
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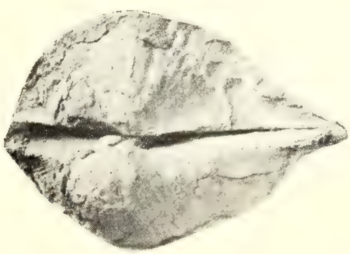
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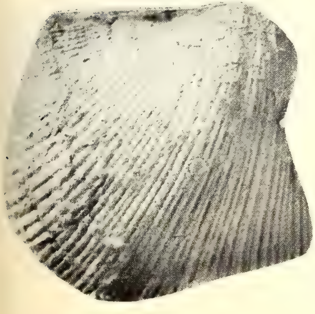
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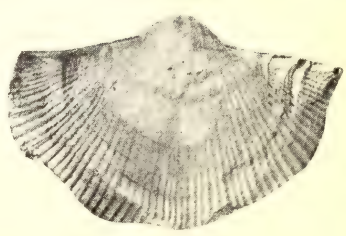
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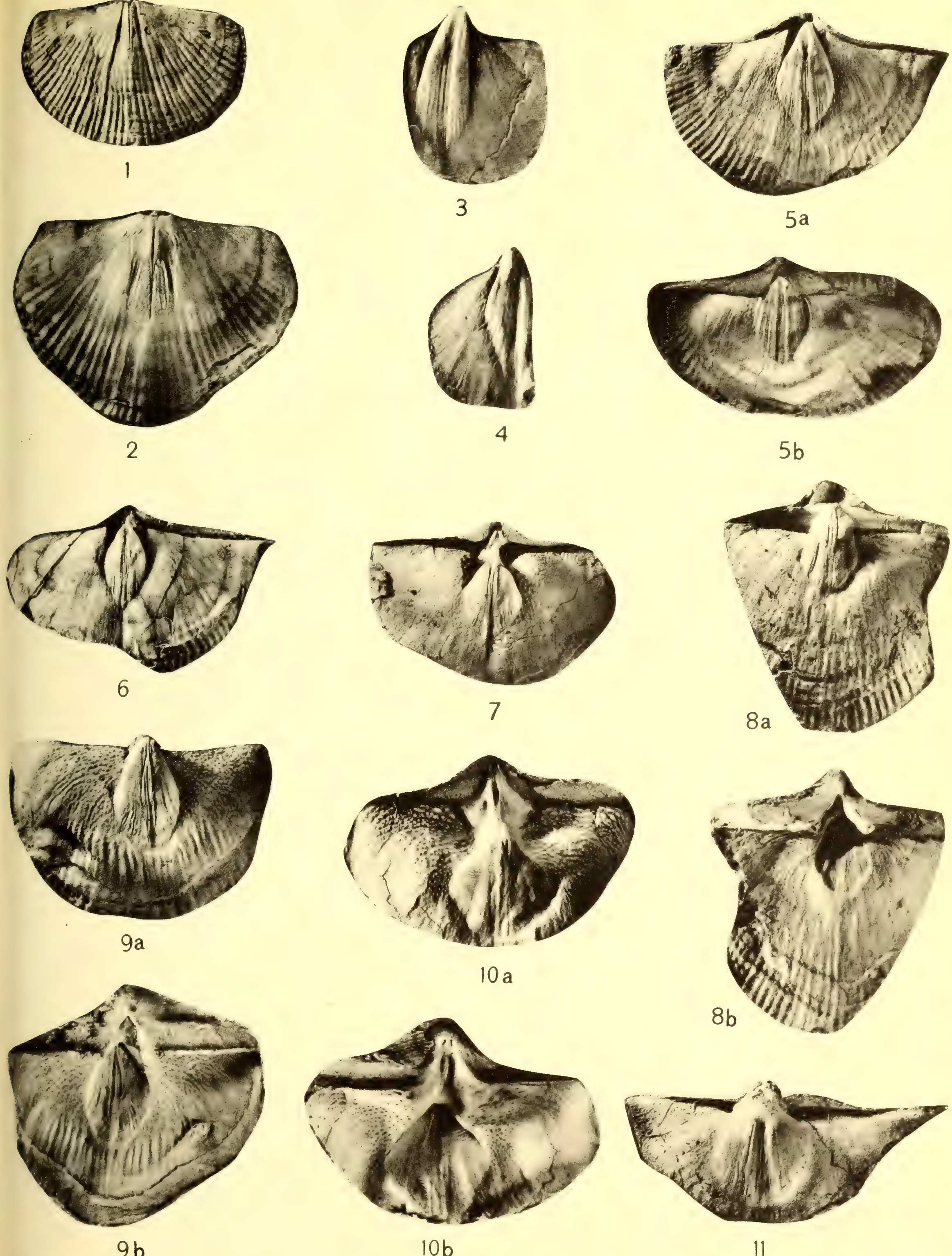
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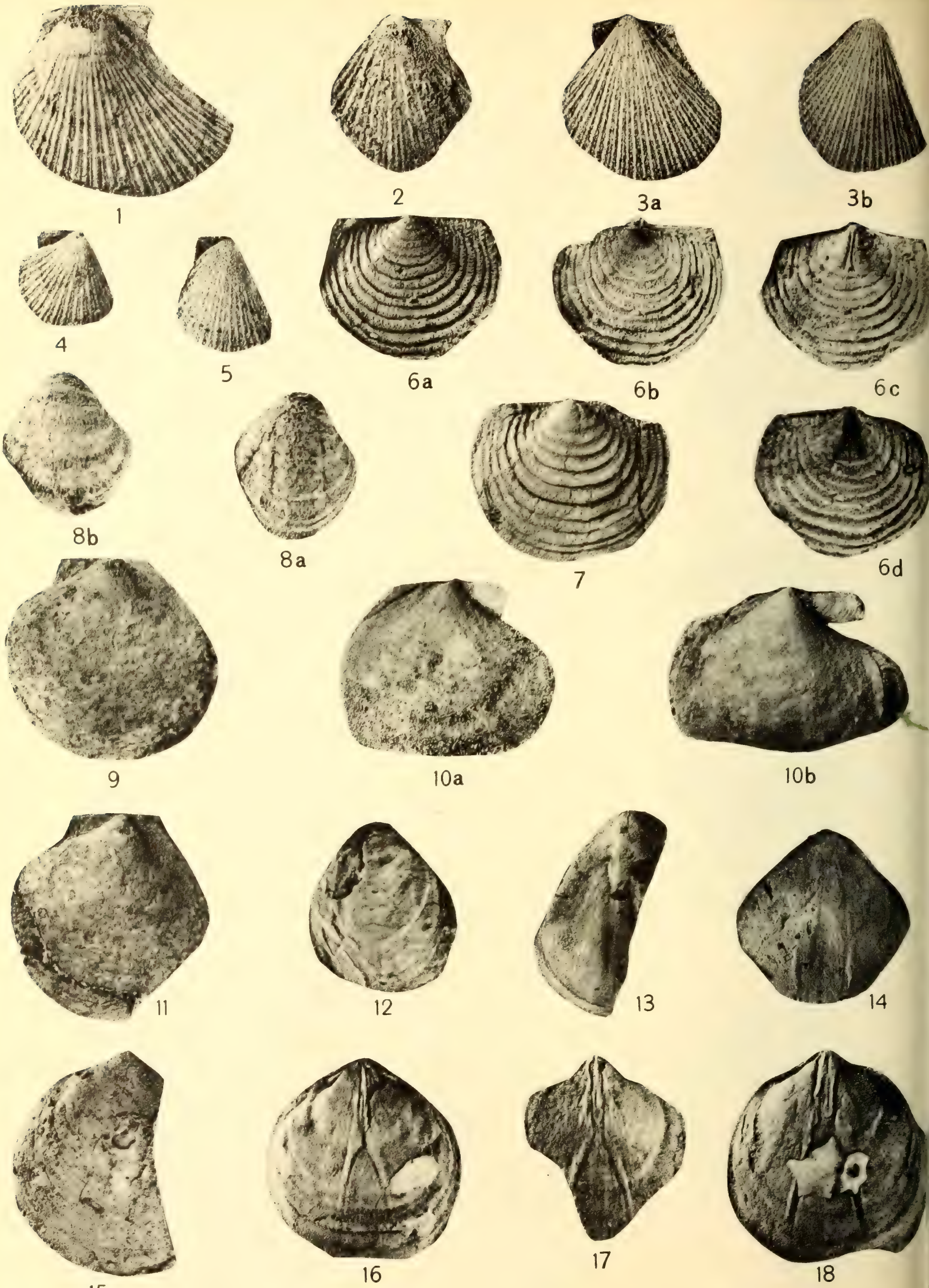
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Royal Society of New South Wales

OFFICERS FOR 1964-1965

NOTICE

The Royal Society of New South Wales originated in 1821 as the "Philosophical Society of Australasia"; after an interval of inactivity it was resuscitated in 1850 under the name of the "Australian Philosophical Society", by which title it was known until 1856, when the name was changed to the "Philosophical Society of New South Wales". In 1866, by the sanction of Her Most Gracious Majesty Queen Victoria, the Society assumed its present title, and was incorporated by Act of Parliament of New South Wales in 1881.

THE ROYAL SOCIETY OF NEW SOUTH WALES SYDNEY
FOUN. 1821. INC. 1881

AUSTRALASIAN MEDICAL PUBLISHING CO. LTD.
SEAMER AND ARUNDEL STS., GLEBE, SYDNEY

JOURNAL AND PROCEEDINGS

OF THE

ROYAL SOCIETY OF NEW SOUTH WALES

VOLUME 97 1964 PART 6B

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ISSUED JULY 28, 1965

Registered at the General Post Office, Sydney, for transmission by post as a periodical

NOTICE TO AUTHORS

General. Manuscripts should be addressed to the Honorary Secretaries, Royal Society of New South Wales, 157 Gloucester Street, Sydney. Two copies of each manuscript are required: the original typescript and a carbon copy; together with two additional copies of the abstract typed on separate sheets.

Papers should be prepared according to the general style adopted in this Journal. They should be as concise as possible, consistent with adequate presentation. Particular attention should be given to clarity of expression and good prose style.

The typescript should be double-spaced, preferably on quarto paper, with generous side margins. Headings should be typed without underlining; if a paper is long, the headings should also be given in a table of contents typed on a separate sheet, for the guidance of the Editor.

The approximate positions of Figures, Plates and Tables should be indicated in the text between parallel ruled lines. Captions of Figures and Plates should be typed on a separate sheet.

The author's institutional or residential address should be given in the title of the paper, the relevant author's initials being attached in brackets to the appropriate address in cases of papers written jointly.

Abstract. An *informative* abstract should be provided at the commencement of each paper for the guidance of readers and for use in abstracting journals.

Tables. Tabular matter should be typewritten on separate sheets, arranged for the most economical presentation on the printed page. Column lines should *not* be ruled in. Units of measurement should always be indicated in the headings of the columns or rows to which they apply. Tables incorporating both text and line diagrams (including dotted lines and shading) should be submitted in a form suitable for direct reproduction by photographic line blocks.

References. References are to be cited in the text by giving the author's name and the year of publication, e.g.: Vick (1934); at the end of the paper they should be arranged alphabetically giving the author's name and initials, the year of publication, the title of the paper (if desired), the abbreviated title of the journal, volume number and pages, thus:

Vick, C. G., 1934. *Astr. Nach.*, **253**, 277.

The abbreviated form of the title of this journal is: *J. Proc. Roy. Soc. N.S.W.*

Captions of Figures and Plates should be typed in numerical order on a separate sheet.

Line Diagrams. Line diagrams, fully lettered, should be made with dense black ink on either white bristol board, blue linen or pale-blue ruled graph paper. Tracing paper is unsatisfactory because it is subject to attack by silverfish and also changes its shape in sympathy with the atmospheric humidity. The thickness of lines and the size of letters and numbers should be such as to permit photographic reduction without loss of detail.

Dye-line or photographic copies of each diagram should be sent so that the originals need not be sent to referees, thus eliminating possible damage to the diagrams while in the mail.

Photographs. Photographs should be included only where essential, should be glossy, preferably mounted on white card, and should show as much *contrast* as possible, since contrast is lost in reproduction of half-tone blocks. Particular attention should be paid to contrast in photographs of distant scenery and of geological subjects. When several photographs are to be combined in one Plate, the photographs should be mounted on a sheet of white bristol board in the arrangement desired for final reproduction.

Geological Papers. Except in special circumstances, authors submitting manuscripts in which new stratigraphical nomenclature is proposed must also submit the letter of approval of or comment on the new names from the appropriate nomenclature sub-committee of the Geological Society of Australia.

Reprints. Authors who are members of the Society receive 50 copies of each paper free. Additional copies may be purchased provided they are ordered by the author when returning galley-proofs.

THE AUTHORS OF PAPERS ARE ALONE RESPONSIBLE FOR THE STATEMENTS MADE AND THE OPINIONS EXPRESSED THEREIN.

Annual Reports

Report of the Council for the Year Ended 31st March, 1964

Presented at the Annual and General Monthly Meeting of the Society held 1st April, 1964

At the end of the period under review the composition of the membership was 358 members, 18 associate members and 9 honorary members; 18 new members were elected. Eight members resigned and the names of one member and one associate member were removed from the list of members under Rule XVIII.

It is with extreme regret that we announce the loss by death of the following eminent members:

Dr. Edgar H. Booth (elected 1920).
Professor Richard C. L. Bosworth (elected 1939).
Emeritus Professor Leo A. Cotton (elected 1909).
Emeritus Professor Harvey Sutton (elected 1920).

At the meeting of the Council held on 24th April it was decided to offer Life Membership to Mr. J. W. Hogarth " in view of meritorious service to Chemistry in the City of Sydney over a large number of years ". This is the only occasion on which Life Membership has been offered to a member.

Nine monthly meetings were held. The abstracts of all addresses have been printed on the notice papers. The proceedings of these follow. The members of the Council wish to express their sincere thanks and appreciation to the nine speakers who contributed to the success of these meetings, the average attendance being 37.

The Annual Social Function was held on 19th March at the Sydney University Staff Club and was attended by 54 members and guests.

The Council has approved of the following awards:

The Clarke Medal for 1964 to Dr. Joyce W. Vickery, M.B.E., of the National Herbarium.

The Society's Medal for 1963 to Prof. R. S. Nyholm, F.R.S., of London University College.

The Edgeworth David Medal for 1963 to Prof. N. H. Fletcher, of the University of New England.

The James Cook Medal was not awarded.

The Archibald D. Ollé Prize was not awarded.

The Donovan Astronomical Lecture for 1963, given under the auspices of the Royal Society of New South Wales and the N.S.W. Branch of the British Astronomical Association, entitled " Positional Astronomy ", was delivered by Mr. Harley Wood, Government Astronomer, Sydney Observatory. This lecture has been published in the *Journal and Proceedings*, v. 97, pp. 135–144.

The Society has again received a grant from the Government of New South Wales, the amount being £750. The Government's interest in the work of the Society is much appreciated.

The Society's financial statement shows a surplus of £2,211 11s. 7d., of which £2,192 10s. 6d. was the result of sales of surplus library stock, leaving as a true surplus the amount of £19 1s. 1d.

The *New England Branch* of the Society held six meetings and the Proceedings of the Branch follow.

The *President* was to represent the Society at the Commemoration of the Landing of Captain Cook at Kurnell. The proceedings were cancelled due to inclement weather. The President attended an exhibition of paintings of Australia and the Pacific in the Mitchell and Dixon Galleries of the Public Library of New South Wales.

Both Mr. McKern and Dr. Low were present at the opening of the New Wing of the Australian Museum.

The President attended the Annual Meeting of the Board of Visitors of the Sydney Observatory.

On 12th July, the President and the Honorary Secretary waited on His Excellency the Governor of New South Wales.

The Society's representatives on Science House Management Committee were Mr. C. L Adamson and Mr. H. A. J. Donegan, the alternative representatives being Mr. Conaghan and Dr. Low.

Six parts of the *Journal and Proceedings* have been published during the year.

Due to costs of publication, Council decided, with regret, to wind up the *Monograph Fund* and to revert the funds to the General Purpose Account of the Society.

The *Section of Geology* held five meetings, and abstracts of the proceedings will be published later.

Council held eleven ordinary meetings. Five special meetings were held to discuss alterations to the Rules. Attendance was as follows: Mr. H. H. G. McKern 16; Mr. J. L. Griffith 14; Prof. R. J. W. Le Fevre (absent on leave for 4 meetings) 3; Mr. W. H. G. Poggendorff 7; A/Prof. W. B. Smith-White 7; Dr. A. H. Low 16; Dr. A. A. Day 14; Mr. C. L. Adamson 12; Dr. Ida A. Browne 11; Mr. H. F. Conaghan 12; Father A. G. Fynn 10; Dr. N. A. Gibson (absent on leave for 7 meetings) 3; Mr. H. G. Golding 6; Mr. J. W. Humphries 14; Dr. A. Keane 13; Mr. J. Middlehurst 8: Dr. R. L. Stanton 1; Dr. A. Ungar (absent on leave for 3 meetings) 4.

A major undertaking of the Council was a complete revision of the Rules. To this end a sub-committee was formed to which Mr. A. F. A. Harper was co-opted.

The Library—Periodicals were received by exchange from 398 societies and institutions. In addition an amount of £105 0s. 3d. was expended on the purchase of 11 periodicals.

Mr. A. F. Day resigned from the position of Assistant Librarian on 24th March. Due to Mr. Day's efforts the reorganization of the library has now been completed.

Renovations to the office and library carried out during the year included painting and new floor covering.

Among the institutions which made use of the library through the inter-library loan scheme were:

N.S.W. Govt. Depts.—Department of Main Roads, Department of Mines, Department of Public Health,

State Fisheries, Sydney County Council, Water Conservation & Irrigation Commission, Division of Wood Technology.

Commonwealth Govt. Depts.—C.S.I.R.O. Library, Canberra ; Chemical Research Laboratories, Melbourne; Division of Animal Physiology, Prospect ; Division of Building Research, Highett ; Division of Coal Research, Ryde ; Division of Fisheries & Oceanography, Cronulla ; Division of Food Preservation, Ryde ; Division of Plant Industry, Canberra ; National Standards Laboratory, Sydney ; Division of Textile Physics, Ryde ; Australian Atomic Energy Commission ; Bureau of Meteorology ; Bureau of Mineral Resources, Geology & Geophysics ; Commonwealth Acoustic Laboratory ; Department of the Army.

Universities and Colleges—Sydney Technical College ; Newcastle University College ; Townsville University College ; Teachers' College, Wagga ; Australian National University ; University of Adelaide ; Monash University ; University of New England ; University of New South Wales ; University of Queensland ; University of Tasmania.

Companies—Adastra-Hunting Geophysics ; Alginates Pty. Ltd. ; Australian Consolidated Industries : Australia Electrical Industries ; Australian Gaslight Co. Ltd. ; Australian Iron and Steel Ltd. ; B.H.P. Co. Ltd. ; C.S.R. Co. Ltd. ; Commonwealth Industrial Gases ; Johnson & Johnson ; Lysaght Ltd. ; Mauri Bros. & Thompson Pty. Ltd. ; Phillips Electrical Industries ; Stawfer Chemical Co. ; Titan Manufacturing Co. ; Wheat Industries (Aust.) Pty. Ltd. ; W.D. & H.O. Wills Ltd.

Research Institute—Bread Research Institute.

Museum—The Australian Museum.

Miscellaneous—Australian Medical Association ; Institution of Engineers, Aust. ; Linnean Society of New South Wales ; The Reserve Bank ; Standards Association of Australia ; Department of Works, Brisbane ; The Government Geologist, Brisbane ; Geological Survey of Western Australia.

Total borrowings—517 items.

A. H. Low
A. A. Day
Hon. Secretaries.

Financial Statement

BALANCE SHEET AS AT 29th FEBRUARY, 1964

LIABILITIES

1963		£	s.	d.	£	s.	d.
1,000	Accrued Expenses				—		
26	Subscriptions Paid in Advance				30	9	0
97	Life Members' Subscriptions — Amount carried forward				89	5	0
	Trust and Monograph Capital Funds (detailed below)—						
	Clarke Memorial	2,092	4	7			
	Walter Burfitt Prize	1,164	1	4			
	Liversidge Bequest	714	0	6			
	Monograph Capital Fund	—					
8,760	Ollé Bequest	223	17	7			
					4,194	4	0
22,839	Accumulated Funds				29,692	15	4
160	Employees' Long Service Leave Fund Provision ..				184	19	8
	Contingent Liability (in connection with Perpetual Lease).						
£32,882					£34,191	13	0

ASSETS

1963		£	s.	d.	£	s.	d.
1,986	Cash at Bank and in Hand				2,858	15	3
	Investments—						
	Commonwealth Bonds and Inscribed Stock— At Face Value—held for :						
	Clarke Memorial Fund	1,800	0	0			
	Walter Burfitt Prize Fund	1,000	0	0			
	Liversidge Bequest	700	0	0			
	General Purposes	5,160	0	0			
8,460					8,660	0	0
160	Fixed Deposit—Long Service Leave Fund ..				184	19	8
	Debtors for Subscriptions	116	13	0			
	Less Reserve for Bad Debts	116	13	0			
—					—		
14,835	Science House—One-third Capital Cost				14,835	4	4
6,800	Library—At Valuation				6,800	0	0
626	Furniture and Office Equipment—At Cost, *less* Depreciation				838	8	0
14	— Pictures—At Cost, *less* Depreciation				13	5	9
1	Lantern—At Cost, *less* Depreciation				1	0	0
£32,882					£34,191	13	0

TRUST AND MONOGRAPH CAPITAL FUNDS

	Clarke Memorial			Walter Burfitt Prize			Liversidge Bequest			Ollé Bequest		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Capital at 29th February, 1964 ..	1,800	0	0	1,000	0	0	700	0	0	—		
Revenue—												
Balance at 28th February, 1963 ..	214	0	8	195	14	11	*16*	*10*	*3*	181	12	7
Income for twelve months	78	8	11	43	11	5	30	10	9	42	5	0
	292	9	7	239	6	4	14	0	6	223	17	7
Less Expenditure	0	5	0	75	5	0	—			—		
Balance at 29th February, 1964 ..	£292	4	7	£164	1	4	£14	0	6	£223	17	7

ACCUMULATED FUNDS

	£	s.	d.	£	s.	d.
Balance at 28th February, 1963				22,839	2	5
Add—						
Transfer of Monograph Capital Fund ..				3,000	0	0
Monograph Fund—Revenue Account ..				1,688	9	4
Sundry Receipt				0	15	0
Surplus for Twelve Months				2,211	11	7
				29,739	18	4
Less—						
Increase in Reserve for Bad Debts ..	17	8	6			
Transfer for Long Service Leave Fund Provision	25	0	0			
Subscriptions Written Off	4	14	6			
				47	3	0
				£29,692	15	4

Auditors' Report

The above Balance Sheet has been prepared from the Books of Account, Accounts and Vouchers of The Royal Society of New South Wales, and is a correct statement of the position of the Society's affairs on 29th February, 1964, as disclosed thereby. We have satisfied ourselves that the Society's Commonwealth Bonds and Inscribed Stock are properly held and registered.

HORLEY & HORLEY,
Chartered Accountants.

Prudential Building,
39 Martin Place, Sydney,
19th March, 1964.

Registered under the Public Accountants
Registration Act 1945, as amended.

(Sgd.) C. L. ADAMSON,
Honorary Treasurer.

INCOME AND EXPENDITURE ACCOUNT

1st March, 1963, to 29th FEBRUARY, 1964

1963					£ s. d.
2	Advertising				—
6	Annual Social				11 3 8
38	Audit				37 16 0
9	Branches of the Society				50 0 0
106	Cleaning				104 0 0
34	Depreciation				44 17 3
66	Electricity				69 2 7
4	Entertainment				3 12 0
35	Insurance				35 4 2
133	Library Purchases				147 6 10
157	Miscellaneous				161 6 11
169	Postages and Telegrams				131 8 9
	Printing—Journal—				
		Vol. 96, Parts 2–6	£1,296 1 6		
		Vol. 97, Part 1	258 0 0		
		Reprints	240 2 8		
		Postages	64 18 8		
		Binding	4 8 0		
				1,863 10 10	
		Less—			
		Provision for Vol. 96, Parts 2–6	1,000 0 0		
		Sale of Reprints	87 4 10		
		Subscriptions (to Journal)	255 12 2		
		Back Numbers	97 0 11		
		Refund Postages	14 17 9		
				1,454 15 8	
1,234					408 15 2
216	Printing—General				186 13 0
986	Rent—Science House Management				1,038 12 6
6	Repairs				63 16 2
1,439	Salaries				1,425 7 6
37	Telephone				39 6 0
—	Surplus for the Twelve Months				2,211 11 7
£4,677					£6,170 0 1

1963		£ s. d.
956	Membership Subscriptions	954 19 6
7	Proportion of Life Members' Subscriptions	7 10 0
750	Government Subsidy	750 0 0
2,059	Science House Management—Share of Surplus	2,023 12 8
109	Interest on General Investments	234 8 5
676	Sale of Periodicals *ex* the Library	2,192 10 6
2	Donations	4 4 0
—	Sundry Receipts	2 15 0
118	Deficit for Twelve Months	—
£4,677		£6,170 0 1

Obituary

Edgar Harold Booth, M.C., D.Sc., a member of the Society since 1920, and President in 1936–37, died in Sydney on 18th December, 1963, at the age of 70. The son of James Booth, formerly of Montrose in Scotland, Dr. Booth was born in Sydney on 12th February, 1893, and was educated at the Fort Street School, Observatory Hill, and the University of Sydney. He graduated Bachelor of Science in Physics and Mathematics in 1914. In 1915 he was appointed Assistant Lecturer and Demonstrator in Physics in the University of Sydney but resigned in the same year to join the A.I.F., with which he served in France and Belgium until 1919. He won the Military Cross in action at Ypres in 1917 and was also mentioned in dispatches.

From 1919 to 1937 Dr. Booth was Lecturer in Physics at the University and during this period took an active interest in the methods of geophysical exploration which were just beginning to be applied to the search for mineral resources in Australia. From 1929–1931 he acted as a consultant to the seismic section of the Imperial Geophysical Experimental Survey which carried out a series of pioneer test surveys; the results were published in 1931. The developments he further discussed in his Presidential address to this Society, while in 1935 he submitted a paper on a magnetic survey of the Mt. Gibraltar district surrounding his country residence, "Hills and Dales", Mittagong.

In 1931, with Miss P. M. Nicol, he published the textbook "Physics, Fundamental Laws and Principles" which has been used by many generations of students and reached its sixteenth edition in 1962. In 1932 he published "Elementary Physics", which also ran to a number of editions.

The Government of New South Wales appointed him consulting physicist in 1930. In 1936 he was awarded the degree of D.Sc. by the University of Sydney.

In 1937 Dr. Booth was appointed by the University as a Warden, to be responsible for the formation, direction and control of a College to be called the University College of New England. To him belongs much of the credit for the successful establishment of the College and for the impact which the College had on the spread of education in northern New South Wales. He remained in this position until 1945.

His diverse talents were now to be exhibited in an environment of a kind totally different from that in which he had moved hitherto, for in 1945 he accepted an invitation to become the overseas representative of the Australian Wool Board and chairman of the International Wool Secretariat. While in London he became a Vice-President of the Incorporate Society of London Fashion Designers and took a keen interest in promoting the use of wool by leading designers. In 1948 he was forced by ill-health to resign his appointment and returned to Australia.

From 1950 he was at various times a member of the Councils of the Standards Association of Australia, the National Research Council of Australia and the Australian and New Zealand Association for the Advancement of Science.

In 1924 Dr. Booth married Jessie Wilcox and she, a son and a daughter survive him.

Richard Charles Leslie Bosworth was born in 1908 and died on 24th March, 1964.

The late Professor Bosworth was educated at the University of Adelaide, South Australia. In 1933 he was awarded an 1851 Exhibition Scholarship and proceeded to Trinity College, Cambridge, England, where he worked under Sir Eric K. Rideal for five years, receiving his Ph.D. from Cambridge University in 1935. In 1938 he received the degree of D.Sc. from the University of Adelaide.

After returning to Australia in 1938 he was appointed Research Chemist to the Colonial Sugar Refining Co. Ltd., Sydney, N.S.W., and in 1948 became Manager of this company's Research Department, which position he held until he resigned in January, 1957, to take up the appointment at the University of New South Wales on 12th March, 1957, as Associate Professor and Head of the Department of Physical Chemistry, which position he held at the time of his death.

He was guest Professor to the University of Canterbury, New Zealand, and guest lecturer to the New Zealand Chemical Society, Auckland, in September, 1961.

He attended the conference at Hobart in February, 1963, of the Electro-Chemical Society, and was on the Executive Committee.

The late Professor was to have been the guest speaker at the British Rheological Meeting at Brown University, U.S.A., but owing to ill-health could not attend, but his paper was read and is now in the process of being published by Pergamon Press.

He also had accepted a visiting Professorship to the University of Illinois, U.S.A., for 1962, but had to withdraw on account of ill health. He was offered the position of Head of the School of Chemical Engineering at Monash University, Victoria, but had to turn down the invitation on account of ill health.

In 1951, Professor Bosworth was joint participant in the award of the H. G. Smith Memorial Medal and in 1957 he was awarded the Medal of the Royal Society of New South Wales for his distinguished contributions and services to the Society.

A member of the Royal Society of New South Wales since 1939, he served on the Council as an ordinary member and as Honorary Secretary and was elected President in 1951.

Publications

Papers published in the Journal and Proceedings of the Royal Society of New South Wales:

1940 Adsorption of Hydrogen by an Ideal Metal, v. 74, pp. 538–548.

1944 Bessel's Formula in relation to the calculation of the probable error from a small number of observations, v. 78, pp. 81–83.
Thermal Conductivity from Measurements of Convection, v. 78, pp. 220–225.

1945 Contact Potential Difference as a Tool in the Study of Adsorption, v. 79, pp. 53–62.
Radiant Heat Loss as a Problem in Effusion, v. 79, pp. 63–66.
A Convenient Vacuum Method for the Preparation of Nitrogen, v. 79, pp. 116–117.

1945 Evaporation of Oxygen from a Tungsten Surface, v. 79, pp. 190–195.
Properties of Nitrogen on Tungsten Films, v. 79, pp. 166–171.
1946 A Simple Demonstration of the Difference between Film and Nuclear Boiling, v. 80, pp. 20–21.
1947 Dimensional Methods in the Design of Industrial Chemical Research, v. 81, pp. 15–23.
A New Method for the Comparison of the Thermal Conductivities of Fluids, Pt. 1, v. 81, pp. 156–166.
A New Method for the Comparison of the Thermal Conductivities of Fluids, Pt. 2, v. 81, pp. 210–215.
Corrosion of Surfaces Heated Above the Boiling Point of the Corrodant, v. 81, pp. 206–209.
1948 The Incomplete Nature of the Symmetry Relations between Thermodynamical Quantities, v. 82, pp. 175–182.
The Concepts of Resistance, Capacitance and Inductance in Thermal Circuits, v. 82, pp. 211–217.
1949 The Effect of Diffusional Processes on the Rate of Corrosion, v. 83, pp. 8–16.
The Influence of Forced Convection on the Process of Corrosion, v. 83, pp. 17–24.
The Influence of Natural Convection on the Process of Corrosion, v. 83, pp. 25–30.
The Formation of Mobile and Immobile Films of Oxygen on Tungsten, v. 83, pp. 31–38.
A Note on the Sigma Phenomenon, v. 83, pp. 39–43.
Anodic and Cathodic Polarisation of Copper in Acetic Acid, v. 83, pp. 124–133.
(with P. R. Johnson) A New Method of Measurement of the Surface Tension of Viscous Liquids, v. 83, pp. 164–169.
1950 The Five Properties Concerned in the Transport of the Active Corrodant Agent, v. 84, pp. 53–58.
1952 Presidential Address: Transport Processes in Applied Chemistry, v. 86, pp. 3–13.
1960 (with C. M. Groden) Kinetics of Chain Reactions, v. 94, pp. 99–108.
1962 (with C. M. Groden) Conditions for Stability in Chain Reactions, v. 95, pp. 189–194.

Books Published:

"Physics in Chemical Industry", MacMillan & Co., London (1950).

"Heat Transfer Phenomena", Associated General Publications Ltd., Sydney. John Wiley, Inc., New York (July, 1952).

"Transport Processes in Applied Chemistry", Associated General Publications Ltd., Sydney. John Wiley, Inc., New York (April, 1956).

Contributor to: "Principles of Sugar Technology", edited by P. Honig, published by Elsevier Publishing Co., N.Y., Amsterdam, London, New York, Princeton—"Determination of Heat Transmission as an Indirect Method for the Determination of the Viscosity and Supersaturation of Technical Sugar Solutions", Chapter 8, Volume II, 1959; and "Heat Transfer", Chapter 1, Volume III, 1963.

Further Publications:

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Leo Arthur Cotton, M.A., D.Sc., Edgeworth David Professor of Geology and Physical Geography (1925–1948) and Professor Emeritus since 1949, died in Sydney on 12th July, 1963.

Son of Francis Cotton, engineer and inventor, Leo Arthur Cotton was born at Nymagee (N.S.W.) on 11th November, 1883. When fourteen years of age, he came to Sydney with his parents and entered Fort Street High School where, however, his studies were interrupted by the family's temporary translation to the Forbes and Hillgrove districts. Later he resumed his studies at the same school and in March, 1903, matriculated as an evening student in the Faculty of Arts of the University of Sydney.

After a distinguished undergraduate career, Leo Cotton graduated in 1906 as Bachelor of Arts with First Class Honours in Mathematics. Entering the Faculty of Science, he graduated as Bachelor of Science in 1908 with First Class Honours in Geology-Mineralogy, being awarded in this period the Smith Prize in Physics, the Slade Prize for Practical Physics, the Professor David Prize for Geology, the Deas-Thompson Scholarship in Physics, the Deas-Thompson Scholarship in Geology, and the John Coutts Scholarship for distinction in Science.

In December, 1907, Leo Cotton became a member of the Shackleton Antarctic Expedition, sailing from Lyttleton (N.Z.) in the "Nimrod", and returning in March, 1908, to take up his duties as Demonstrator in Geology, University of Sydney, where Dr. Woolnough was acting as head of the Department during the absence of Professor David occasioned by his exploration and scientific work in Antarctica.

In 1909 Leo Cotton was awarded a Linnean Macleay Research Fellowship which he held for two years while engaged in an investigation of ore deposition with particular reference to the New England district.

In 1911 he was appointed to the permanent establishment of the Department of Geology of the University of Sydney as Lecturer and Demonstrator, beginning a long period of distinguished University service. His appointment as Assistant Professor in 1920 made public acknowledgement of his outstanding work as Acting Head of the Department of Geology during the absence of Professor David on War Service overseas in the period January, 1916, to April, 1919. Leo Cotton's appointment in 1925 as Professor and Head of the Department of Geology in succession to Professor Sir Edgeworth David was a fine tribute to his evident qualities as a scientist and leader, further proven in 1921 and 1923–24 when he had again acted as Head of the Department of Geology during the absence of Professor David. In addition to his outstanding work as Professor and Head of the Department of Geology over a period of twenty-four years, Leo Cotton served with distinction as Dean of the Faculty of Science between 1944 and 1946.

Despite extended periods of considerable and often difficult responsibility, Leo Cotton nevertheless established and developed an outstanding reputation for scholarship. His research interests lay particularly in the mathematical aspects of geology and geophysics. In 1916 he was awarded the degree of Master of Arts in Mathematics, and in 1920 received the degree of Doctor of Science with First Class Honours and the

LEO A. COTTON, M.A., D.Sc.

University Medal, for his thesis entitled "Earthquake Frequency with Special Reference to Tidal Stresses in the Lithosphere".

He represented the University of Sydney at the First Pan-Pacific Science Congress at Honolulu in 1920, and the Third Congress at Tokyo in 1926; he was also Secretary of the Geology Section at the Second Pan-Pacific Congress which met in Sydney in 1923.

He was elected to membership of the Royal Society of New South Wales in 1909, was President in 1929 and served on the Council of the Society for a number of years.

During his active geological career, Leo Cotton was a Fellow of the Geological Society of London, A Fellow of the Geological Society of America, and a member of the Linnean Society of New South Wales. He delivered the Clarke Memorial Lecture to the Royal Society in 1946.

As a member of the Australian National Research Council, Leo Cotton served on many scientific committees, including those on Seismology and Geodesy and Geophysics. For several years he was an active member of the Editorial Sub-Committee of the parent body, and Chairman of the Council in 1943. Professor Cotton was also actively concerned in the affairs of the Australian Association for the Advancement of Science, being Vice-President of Section C in 1923 (Wellington) and 1924 (Adelaide) and President of the Section in 1928 (Hobart); in 1937 he was elected a Fellow of the Association. The distinction of Honorary Membership of the Geological Society of Australia was conferred upon him in 1958.

During World War II, Professor Cotton was Chairman of the Advisory Committee on Scientific Manpower (General).

The new L. A. Cotton School of Geology of the University of New England, so named in honour of the man and his outstanding contributions to the geological sciences in Australia, was opened by him in 1960, a most fitting tribute to his life and work.

Florence Channon, whom Leo Cotton married in 1910, died in 1930 leaving with him their three sons and two daughters, consolation and responsibility accepted and fulfilled to the utmost of his warm and generous nature. In 1946 he married Lilian Read, with whom he enjoyed many years of quiet retirement in their home at Newport.

Other than family, professional and academic interests, Leo Cotton enjoyed as recreations lawn bowls and chess, at which he was particularly skilled.

In both his private and professional life, Leo Cotton was a gentle, most considerate and understanding man, whose friendship and counsel were sought by many and valued most highly by all those who had the privilege of knowing him well.

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Emeritus Professor **Harvey Sutton**, O.B.E., M.D., Ch.B., B.Sc., F.R.S.H., F.R.A.C.P., who was formerly Director of the School of Public Health and Tropical Medicine and Professor of Preventive Medicine in the University of Sydney, died at his home in Sydney on 21st June, 1963, at the age of 81.

Professor Sutton was born in Victoria. He received his early education at St. Andrew's College, Bendigo, and proceeded as a medical student to the University of Melbourne. He graduated M.B., Ch.B. in 1902, having gained honours in every subject and the Scholarship in Pathology.

He had a distinguished record as a sportsman, for he excelled in most games. He represented his University in lacrosse, athletics and cricket, and Trinity College in rowing, cricket, football and athletics. At various times he held the University half-mile record, the Victorian and Australasian half-mile and Victorian one mile records. He represented Australia in the 1908 Olympiad in London. Also, he represented Oxford University in lacrosse and athletics.

After his graduation Professor Sutton served for two years at the Children's Hospital, Melbourne, and then gained the Rhodes Scholarship for Victoria. He took up residence at New College, Oxford, in 1906, graduating M.D. before he left Melbourne. At Oxford he spent two years under J. S. Haldane in physiology, gaining a research degree in Science. After a period at Charing Cross Hospital he returned to Melbourne.

He had become interested in Public Health, and after qualifying for the D.P.H. he joined the School Medical Service. He became Chief Medical Officer of the Education Department of Victoria and remained in this position until the outbreak of the First World War.

He enlisted in the A.I.F. in 1915 and served with the Australian Light Horse in the desert campaigns in Sinai, Palestine and Syria. He was in the hygiene service at first, reaching the rank of major, and was involved in Allenby's anti-malarial campaign in the Jordan Valley and in the constant fight against epidemic dysentery. He later became D.A.D.M.S. of the ANZAC Mounted Division. He served with distinction, was awarded the O.B.E., and was twice mentioned in dispatches.

On his return from the war Professor Sutton joined the New South Wales Education Department as Principal Medical Officer. He held this position for nine years, and for much of the period he was also part-time Lecturer in Public Health and Preventive Medicine at Sydney University.

In 1930 the Commonwealth Government and the University of Sydney jointly founded the School of Public Health and Tropical Medicine. He became Director of the School and at the same time was appointed by the University to the newly founded Chair of Preventive Medicine. He held these positions until retirement in 1947.

Professor Sutton's teaching was enlivened by wide scholarship and was always entertaining. He gradually extended his instruction beyond the undergraduates and post-graduate studies of the Medical School and introduced courses in hygiene and allied subjects in architecture, social studies, education and physical education. He added colour to the place with his open-air classes, held among the rose hedges of the delightful sunken garden he had designed at the School.

His interests were wide and extended into the personal, family and social aspects of community health and welfare that are now generally called social medicine. His thinking in this was beyond the environmental sanitation and other activities of the health services of the time—that is, of public health as narrowly defined. This was the new public health of which he was an Australian forerunner.

Professor Sutton wrote extensively on a wide range of subjects, especially the development, nutrition, health and welfare of children and young people. Mental hygiene, also the subject of many papers, also claimed his attention and advocacy as both a study and community responsibility. Other publications dealt with climatic physiology, delinquency, alcoholism, public health nursing and the geographical distribution of disease. In 1944 he published a textbook on preventive medicine. Medical history also furnished subjects for a series of papers.

His influence extended beyond the University, and he was associated with most of the local community health and welfare movements of his time. He enthusiastically supported numerous voluntary bodies whose objects were social or health improvement, a number of which he helped to found. He accepted this as an important public responsibility, realising that through its channelling of civic thought and enthusiasm the work of such groups often formed the basis and later testing ground of general advances. From his work in the community, his frequent and assertive public statements on health questions, and the numerous popular lectures which it delighted him to give, he became a public figure, and of the University staff was the one perhaps best known to the man in the street.

Professor Sutton was elected to membership of the Society in 1920. He is survived by his wife and three sons and four daughters.

Thomas Griffith Taylor, Emeritus Professor of Geography of the University of Toronto, Canada, died on 5th November, 1963, at the age of 82. Professor Taylor was born in London, came at the age of 13 with his parents to Sydney, and was educated at Sydney Grammar School, The King's School, Sydney University and Cambridge University. As Physiographer in the Australian Meteorological Service, he was seconded to Capt. Scott's Antarctic Expedition in 1910.

He was a pioneer of academic geography in three countries. In 1921 he was appointed Associate Professor of Geography in the University of Sydney, in 1928 Professor of Geography in the University of Chicago, and in 1935 Professor of Geography in the University of Toronto, where he remained until retirement in 1950. He returned to Sydney and added

some further publications to his already large tally of books and papers (some 40 of the former). One of these later writings was "Sydneyside Scenery" which proved very popular with the growing body of lay persons interested in geology and geomorphology.

Within his lifetime he was honoured in many ways, notably by the University of New England in naming its new Geography Department after him, and by the University of Sydney which bestowed his name on the fine new building in which the Geography Department is housed.

He was a member of the Royal Society of New South Wales in the periods 1921–1928 and 1954–1960 and was a member of its Council. The Society conferred its Medal on him in 1960 in recognition of his outstanding services to science and his work for the Society. Increasing deafness caused him to resign from membership in 1960.

Medallists, 1964

Clarke Medal for 1964

Joyce Vickery, D.Sc., M.B.E.

Joyce Winifred Vickery, a member of the Society since 1935, was born at Homebush, New South Wales, and educated at the Methodist Ladies' College, Burwood, and at the University of Sydney, from which she graduated in 1931 as Bachelor of Science with Honours in Botany. She carried out post-graduate work in the Botany Department for the next five years, receiving the degree of Master of Science in 1933 for research on vegetative reproduction in the insectivorous genus *Drosera* and on aspects of grass seed germination. During the next few years three joint papers with Dr. Lilian Fraser on the ecology of the Upper Williams River and Barrington Tops area were published in the Proceedings of the Linnean Society of New South Wales. This is regarded as most important pioneer work on subtropical rainforest ecology. A study of comparative anatomy of grass leaves during these years led to the realisation of the need for a thorough taxonomic reinvestigation of the native Gramineae.

In August, 1936, Miss Vickery joined the staff of the National Herbarium of New South Wales, where her influence, under the Directorship of Mr. R. H. Anderson, has resulted in a great increase in the quantity and improvement in the standard of taxonomic research as well as in the provision of accurate botanical information to the scientific and general public. Although retaining a wide botanical interest, she has specialised in the taxonomy of Australian grasses, particularly those of her home State, and is known as a foremost authority in this field. This has involved periods of work at the Royal Botanic Gardens, Kew, the United States National Herbarium, Washington, and other institutions abroad. Among her many papers are Australia-wide revisions of *Festuca, Deyeuxia, Agrostis, Amphipogon* and *Danthonia*, as well as a treatment of the new genus *Dryopoa* J. Vickery, all published in the Contributions from the New South Wales National Herbarium. In 1959 Joyce Vickery received the degree of Doctor of Science of the University of Sydney, for her published work on grass systematics and in other fields.

Currently, Dr. Vickery, now Special Botanist, is occupied with the continuation of the semi-monographic account of the Gramineae for the new Flora of New South Wales, and is preparing a monograph of the notoriously difficult and ecologically significant genus *Poa* in Australia. Not least among her achievements has been her generous and enlightening assistance to younger botanists and scientific colleagues in her own institution and elsewhere. Editing of the Flora of New South Wales and contributions to the scientific side of conservation work are also among her notable activities.

The Society's Medal for 1963

Professor Ronald S. Nyholm, M.Sc., Ph.D., D.Sc. (Lond.), F.R.A.C.I., F.R.I.C.

Ronald Sydney Nyholm, Professor of Chemistry, University College, London, has been a member of the Society since 1940. He was a member of Council for the years 1944–1948, 1953, and was President in 1954.

Professor Nyholm was born at Broken Hill on 29th January, 1917, and was educated at Broken Hill High School, Sydney University and University College, London.

He was Lecturer and Senior Lecturer in Chemistry at Sydney Technical College, 1940–1951; I.C.I. Fellowship to London University, 1947; and Associate Professor of Inorganic Chemistry, N.S.W. University of Technology, 1952–1954.

In 1952 he was awarded the Corday Morgan Medal and Prize of the Chemical Society of London; in 1955 the H. G. Smith Medal of the Royal Australian Chemical Institute; and he delivered the Chemical Society's Tilden Lecture in 1950.

Professor Nyholm has made many contributions to and greatly increased our understanding of the chemistry of the transition elements, in particular to their stereochemistry, magneto-chemistry and to our knowledge of their unusual oxidation states.

Twenty-six of his papers have been published in the Society's "Journal and Proceedings", and he is one of the contributors to a book entitled "Chelating Agents and Metal Chelates" (Academic Press) which is an all-Australian effort in a field of chemistry to which Professor Nyholm has also made notable contributions.

Edgeworth David Medal for 1963

Professor Neville H. Fletcher

Professor Fletcher is distinguished for his contributions to the physical theory of the solid state.

His early work was concerned with the understanding of the behaviour of transistors and other semi-conductor devices and for the last eight years he has carried out theoretical research into the properties of ice, water and related materials, particularly with regard to the nucleation of ice crystals by foreign substances such as silver iodide, and the behaviour of these in "cloud seeding".

Professor Fletcher already has an international reputation as a cloud physicist, and his book "The Physics of Rainclouds" is regarded as a standard work on the subject.

Abstract of Proceedings, 1963

3rd April, 1963

The ninety-sixth Annual and seven hundred and eighty-second General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Assoc. Prof. W. B. Smith-White, was in the chair. There were present 65 members and visitors.

Frederick A. Everett was elected a member of the Society.

The Annual Report of the Council and the Financial Statement were presented and adopted.

The following awards of the Society were announced :

The Society's Medal for 1962 : Mr. Harley Wood.
The Clarke Medal for 1963 : Dr. Germaine A. Joplin.
The Walter Burfitt Prize for 1962 : Dr. M. F. Glaessner, F.A.A.
The Edgeworth David Medal for 1962 : Mr. R. F. Isbell.

Office-bearers for 1963–64 were elected as follows :

President : H. H. G. McKern, M.Sc.
Vice-Presidents : J. L. Griffith, B.A., M.Sc. ; R. J. W. Le Fevre, D.Sc., F.R.S., F.A.A. ; W. H. G. Poggendorff, B.Sc.Agr. ; W. B. Smith-White, M.A.
Hon. Secretaries : A. H. Low, Ph.D., M.Sc. ; A. A. Day, B.Sc. (Syd.), Ph.D. (Cantab.).
Hon. Treasurer : C. L. Adamson, B.Sc.
Members of Council : Ida A. Browne, D.Sc., H. F. Conaghan, M.Sc., A. G. Fynn, B.Sc., N. A. Gibson, Ph.D., H. G. Golding, M.Sc., J. W. Humphries, B.Sc., A. Keane, Ph.D., J. Middlehurst, M.Sc., R. L. Stanton, Ph.D., A. Ungar, Dr.Ing.

Messrs. Horley & Horley were re-elected as Auditors of the Society for 1963–64.

The retiring President, Assoc. Prof. W. B. Smith-White, delivered his Presidential Address entitled " The Mathematical Sciences in the Changing World ".

Modern living in advanced civilised countries is dependent on a vast application of the results of scientific study of the natural world. The material necessities, comforts and luxuries of our age derive especially from and are by-products of the study of physics, chemistry and geology, the so-called exact sciences. New developments and new applications mount at a fast growing rate. To keep abreast of this progress and to maintain and service existing and expanding facilities civilised states need a greater and greater proportion of their population trained in numerous special techniques of the most varied kinds. This is possible only on the basis of a general scientific education more widely spread and of greater depth than was ever necessary before. So it is that an ever increasing number of people require a scientific education at secondary and tertiary levels. State expenditure in this cause must be seen in a proper perspective. Enormous increases in expenditure cannot be avoided ; no state can afford to be parsimonious with the scientific education of its citizens.

But states, like individuals, must operate within their means. The money spent must be well spent so as to gain the maximum benefits. Education must be efficient. Students must acquire and retain more or less permanently the principles expounded and the skills taught.

All reforms in systems of education are no doubt directed towards gaining greater benefits more efficiently in time and more economically in cost. How can we approximate the best possible results in the domain of the natural sciences?

At the conclusion of the address the retiring President welcomed Mr. H. H. G. McKern to the Presidential Chair.

1st May, 1963

The seven hundred and eighty-third General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. H. G. McKern, was in the chair. There were present 50 members and visitors.

The following were elected members of the Society :

Christine Cienska, Bernard Adrian Howe and Eric Leslie Stevens.

An address entitled " Some Observations on Education in the U.S.S.R." was delivered by A./Prof. J. F. D. Wood, of the School of Mechanical Engineering, the University of New South Wales.

The Soviet educational system : its magnitude, past development and future plans, with special reference to tertiary education.

The control of education in the U.S.S.R. : All-Union Ministry of Higher Education, Republican Ministries of Education.

Secondary education : general and special schools ; boarding schools ; part-time schools ; selection of pupils ; curricula ; manual training ; matriculation.

Trade schools : entrance standard ; length of courses ; quality of production.

Technical colleges : entrance standards ; length of courses ; specialization.

Tertiary education :

Types of institutions : universities ; polytechnic institutes ; specialized institutes.

Courses provided : entrance standards ; nature and length of courses ; full-time, part-time, and correspondence courses ; post-graduate work ; industrial experience.

Student conditions : selection for entry ; scholarships ; sponsorships ; residential facilities ; examinations ; standards ; failure rates ; placement of graduates.

Staff conditions : selection ; promotion ; duties ; salaries.

General conditions : accommodation ; equipment.

5th June, 1963

The seven hundred and eighty-fourth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The senior Vice-President, A./Prof. W. B. Smith-White, was in the chair. There were present 22 members and visitors.

John Francis Rigby was elected a member of the Society.

An address entitled " A World-Wide Standardized Seismograph Network " was delivered by Father A. G. Fynn, S.J., Director of the Riverview College Observatory.

In April, 1960, a committee of American scientists was established by the National Academy of Sciences National Research Council to advise the United States Government on the establishment of a world-wide network of seismographs. The programme which emerged from their deliberations was handed over to the Coast and Geodetic Survey to be carried out.

The purpose of the programme is to encourage and maintain a high degree of international interest and co-operation in the field of seismology with the following immediate aims :

(*a*) A better understanding of the world's seismicity. This knowledge may ultimately lead to better prediction of destructive earthquakes.

(*b*) Greatly improved knowledge of the Earth's crust and mantle, with regard to the number, thickness and nature of the major layers therein.

(*c*) Improved knowledge of wave propagation characteristics through the Earth, including the accurate determination of regional travel times.

(*d*) Improved data for comparison of all types of seismic waves.

Seismograms, written by identical instruments at 125 carefully chosen points, will be transmitted regularly to a Data Centre to be copied and stored. They will be immediately available for study to the world's seismologists.

3rd July, 1963

The seven hundred and eighty-fifth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney.

The President, Mr. H. H. G. McKern, was in the chair. There were present 26 members and visitors.

The following were elected members of the Society : James Edmund Banfield, Paul Coss, Elizabeth Annette Essex, William Eric Smith and Gilbert Percy Whitley.

The Edgeworth David Medal for 1962 was presented to Mr. R. F. Isbell, of C.S.I.R.O., Division of Soils, Cunningham Laboratory, Brisbane, and, following the presentation, Mr. Isbell delivered an address entitled " Land Utilization in Queensland and its relation to Geology, Soil and Climate ".

With several important exceptions, rural land utilization in Queensland is extensive rather than intensive and this is often due to factors other than physical land resources. However, within this broad scale use framework definite land use patterns are evident and the relative importance of geological, soil and climatic factors were considered in relation to the more important rural industries.

The influence of geology lies chiefly in its significance as a soil parent material factor. Soils as such have in some instances determined and delineated certain rural industries but the role of climate is probably of most importance. It is further evident that certain features of the general sub-tropical climate have an important influence on the utilization of many Queensland soils and provide a marked contrast to southern Australia.

7th August, 1963

The seven hundred and eighty-sixth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. H. G. McKern, was in the chair. There were present 20 members and visitors.

The following were elected members of the Society : Kenneth John Brown, Robert William Minns, Ronald James Huntbatch Morris and John Percival Pollard.

An address entitled " Stereo-chemistry of Some Non-metallic Elements and Their Compounds " was delivered by Dr. D. P. Graddon, School of Chemistry, the University of New South Wales.

The molecular structures of most non-metallic elements can be explained on the basis of the 8-n rule, as can those of their compounds with other elements of low electronegativity. When, however, compounds are formed between non-metals and other elements of high electronegativity, such as fluorine, the electronic structure of the non-metal may be expanded beyond that of the next inert gas and the stereochemistry of the compounds formed is determined by the total number of electrons in the expanded valency shell. Examples of both types of behaviour were discussed and extended to include the chemical behaviour of some of the inert gases themselves.

4th September, 1963

The seven hundred and eighty-seventh General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. H. G. McKern, was in the chair. There were present 24 members and visitors.

Gregory Doherty was elected a member of the Society.

An address entitled " Cotton Production in New South Wales " was delivered by Mr. T. E. Kitamura, Special Agronomist (Miscellaneous Crops), Department of Agriculture, N.S.W.

Cotton seed was among the plant material brought to Australia by Captain Arthur Phillip. Since that time, the plant has been cultivated commercially in this country, principally in Queensland.

Although research into the field characteristics and needs of cotton has been conducted over the years by the C.S.I.R.O. and the Queensland and New South Wales Departments of Agriculture, until recently only in Queensland have farmers shown an interest in commercial production. However, during the past five years considerable progress has been made in New South Wales so that in 1962–63 some 2,600 acres of commercial cotton were cultivated.

Although Australian workers are in the happy position of being able to call upon the vast amount of cotton research already completed on a world-wide scale, the application of this information to irrigated cotton under New South Wales conditions poses problems. The solution of these is now being attempted by Departmental workers.

There can be no doubt but that Australia needs this vegetable fibre, nor can there be any question as to the capacity of the environment to support the plant successfully, nor of the ability of farmers to produce it economically.

2nd October, 1963

The seven hundred and eighty-eighth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. H. G. McKern, was in the chair. There were present 56 members and friends.

The following were elected members of the Society : Richard Hugh Macdonald Arnot and Edward Charlton Watton.

The following papers were read by title only: "Some Applications of Aerial Photographs to the Solution of Topographic and Cartographic Problems", by A. D. Albani. "Petrology in Relation to Road Materials, Part II: The Selection of Rock for Road-making in Australia, with special reference to N.S.W.", by E. J. Minty. "Minor Planets Observed at Sydney Observatory during 1962", by W. H. Robertson.

A symposium on "Science or Sciences in Schools. Curriculum for an Integrated Science Course in Schools" was held. The speakers were Mr. M. Bishop, Headmaster of Cranbrook School, and Professor C. E. Marshall, Head of the Department of Geology and Geophysics, the University of Sydney.

Children of secondary school age ought to be given the chance to become aware of the kind of society to which they belong and of which they will become citizens. Their opportunities, understanding, appreciation and preparedness for change in society are diminished wherever their understanding of science and scientists is restricted. Secondary education today must lead as it did in the past to an instructed elite and more importantly than in the past informed citizen.

Science is in its widest sense a humanity and is a compulsory subject under the Wyndham secondary school plan. To achieve the intention of the Wyndham scheme science teachers must think of science as providing for the curriculum; facts—which may be ends in themselves and means to ends; information about men and their activities; data about the development and interplay of ideas. This concept of science stresses at the secondary school level the importance of an understanding and feeling for science and qualifies the importance of an isolated understanding of the data and theories of any one individual science. It challenges the science teachers to re-think their roles in education.

6th November, 1963

The seven hundred and eighty-ninth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. H. G. McKern, was in the chair. There were present 26 members and visitors.

John Robert Conolly was elected a member of the Society.

The following papers were read by title only: "Depositional Environment and Provenance of Devonian and Carboniferous Sediments in the Tamworth Trough, N.S.W.", by K. A. W. Crook; "On the Gibbs Phenomenon in n-Dimensional Transforms", by J. L. Griffith; "*Lepidophloios* and *Cyrtospirifer* from the Lambie Group at Mount Lambie, N.S.W.", by Robin M. Mackay; "Devonian Trilobites from the Wellington-Molong District of New South Wales", by D. L. Strusz.

An address entitled "Air Pollution Research and Control in New South Wales" was delivered by Dr. J. L. Sullivan, N.S.W. Department of Public Health, Division of Occupational Health, Air Pollution Control Branch, Sydney.

Sydney and other industrial cities on the New South Wales coast are subject to substantial air pollution problems which, if uncontrolled, could become severe in future years. Rapid industrial development combined with prolonged subsidence inversions and the Great Dividing Range are the major factors which contribute to the overall patterns, but more public attention has been directed towards specific area problems.

Measurements of various contaminants such as dust-fall, smoke, sulphur dioxide, ozone, polycyclic aromatic hydrocarbons and others have been made in Sydney and elsewhere in New South Wales for several years. Some of these have been made routinely at regular monitoring stations and the results can be correlated with weather patterns and other factors.

Control of air pollution is an engineering problem but legislation is needed in order that industry can have a clear definition of its responsibilities. The philosophy of the approach to the implementation of the New South Wales Clean Air Act by the recently formed Air Pollution Control Branch will be to endeavour to obtain compliance with the legislation without resort to litigation.

4th December, 1963

The seven hundred and ninetieth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. H. G. McKern, was in the chair. There were present 50 members and visitors.

The following papers were read by title only: "Precise Observations of Minor Planets at Sydney Observatory during 1961 and 1962", by W. H. Robertson; "Quaternary Sedimentation by Prior Streams on the Riverine Plain, S.W. of Griffith, N.S.W.", by S. Pels.

An address entitled "Exploration and Development of Australia's Mineral Resources" was delivered by Dr. E. O. Rayner, Assistant Under-Secretary, Department of Mines, N.S.W., Sydney.

The importance of Australia's mineral industry and the requirements and outlook for certain minerals were discussed. Discovery of surface deposits is still possible as attested by recent major finds of iron ore and other minerals. However, exploration is largely passing to large-scale investigations by companies and governmental organizations. The methods employed were reviewed, with particular reference to the search for sub-surface deposits.

Exploration for, and some recent mining developments in, such metals as copper, tin, iron, bauxite, uranium, coal, oil and gas were touched upon, and some examples were illustrated by slides.

Members of the Society, April, 1964

The year of election to membership and the number of papers contributed to the Society's Journal are shown in brackets, thus : (1934 ; P8). * indicates Life Membership.

Honorary Members

BLACKBURN, Sir Charles Bickerton, K.C.M.G., O.B.E., B.A., M.D., Ch.M., Chancellor, University of Sydney. (1960)

BRAGG, Sir Lawrence, O.B.E., F.R.S., The Royal Institution of Great Britain, 21 Albermarle Street, Piccadilly, London, W.1, England. (1960)

BURNET, Sir Frank Macfarlane, O.M., Kt., D.Sc., F.R.S., F.A.A., Director, Walter and Eliza Hall Research Institute, Melbourne. (1949)

FAIRLEY, Sir Neil Hamilton, C.B.E., M.D., D.Sc., F.R.S., 73 Harley Street, London, W.1, England. (1951)

FIRTH, Raymond William, M.A., Ph.D., Professor of Anthropology, University of London, London School of Economics, Houghton Street, Aldwych, W.C.2, England. (1952)

FLOREY, Lord Howard, M.B., B.S., B.Sc., M.A., Ph.D., F.R.S., Professor of Pathology, Oxford University, England. (1949)

O'CONNELL, Rev. Daniel J., S.J., D.Sc., Ph.D., F.R.A.S., Director, The Vatican Observatory, Rome, Italy. (1953)

OLIPHANT, Sir Marcus L., K.B.E., Ph.D., B.Sc., F.R.S., F.A.A., Professor of Physics, Australian National University, Canberra, A.C.T. (1948)

ROBINSON, Sir Robert, M.A., D.Sc., F.R.S., F.C.S., F.I.C., Professor of Chemistry, Oxford University, England. (1948)

Members

ADAMSON, Colin Lachlan, B.Sc., 9 Dewrang Avenue, North Narrabeen. (1944)

ADKINS, George Earl, A.S.T.C., C/o School of Mining Engineering, University of N.S.W., Kensington. (1960)

*ALBERT, Adrien, D.Sc., F.A.A., Professor of Medical Chemistry, Australian National University, Canberra, A.C.T. (1938 ; P2)

ALEXANDER, Albert Ernest, Ph.D., F.A.A., Professor of Chemistry, University of Sydney. (1950)

*ALLDIS, Victor le Roy. (1941)

ANDERSON, Geoffrey William, B.Sc., C/o Box 30, P.O., Chatswood. (1948)

ANDREWS, Paul Burke, B.Sc., 5 Conway Avenue, Rose Bay. (1948 ; P2)

ANNISON, Ernest Frank, Ph.D., F.R.I.C., Senior Lecturer in Chemical Pathology, School of Rural Sciences, University of New England, Armidale. (1961)

ARNOT, Richard Hugh Macdonald, B.A., B.Sc.Agr. (Syd.), Senior Planning Officer, Cumberland County Council, 274 Kent Street, Sydney. (1963)

ASTON, Ronald Leslie, Ph.D., Associate Professor of Geodesy and Surveying, University of Sydney. (1930 ; **President** 1948)

*AUROUSSEAU, Marcel, M.C., B.Sc., 229 Woodland Street, Balgowlah. (1919 ; P2)

BADHAM, Charles David, M.B., B.S., D.R. (Syd.), M.C.R.A., " New Lodge ", 16 Ormonde Parade, Hurstville. (1962)

BAGNALL, Mary, M.A. (Melb.), Mary White College, University of New England, Armidale. (1961)

*BAILEY, Victor Albert, D.Phil., F.A.A., 80 Cremorne Road, Cremorne. (1924 ; P3)

BAKER, Stanley Charles, Ph.D., Department of Physics, Newcastle University College, Tighe's Hill. (1934 ; P4)

BAKER, William Ernest, B.Sc.(Hons.), 394 Kaolin Street, Broken Hill, N.S.W. (1962)

BANFIELD, James Edmund, M.Sc., Ph.D. (Melb.), Department of Organic Chemistry, University of New England, Armidale. (1963)

BANKS, Maxwell Robert, B.Sc., Department of Geology, University of Tasmania, Hobart, Tas. (1951)

*BARDSLEY, John Ralph, 29 Walton Crescent, Abbotsford. (1919)

BASDEN, Kenneth Spencer, Ph.D., B.Sc., Department of Fuel, University of N.S.W., Kensington. (1951)

BAXTER, John Philip, C.M.G., O.B.E., Ph.D., F.A.A., Vice-Chancellor and Professor of Chemical Engineering, University of New South Wales, Kensington. (1950)

BEAVIS, Margaret, B.Sc., Dip.Ed., 2/94 Beach Street, Coogee. (1961)

BECK, Julia Mary (Mrs.), B.Sc., Department of Geophysics, University of Western Ontario, London, Ont., Canada. (1950)

BELL, Alfred Denys Mervyn, B.Sc.(Hons.), School of Applied Geology, University of New South Wales, Kensington. (1960)

*BENTIVOGLIO, Sydney Ernest, B.Sc.Agr., 42 Telegraph Road, Pymble. (1926)

*BISHOP, Eldred George, 26A Wolseley Road, Mosman. (1920)

BLANKS, Fred Roy, B.Sc., 19 Innes Road, Greenwich. (1948)

BLUNT, Michael Hugh, M.R.C.V.S., Veterinary Surgeon, 185 Markham Street, Armidale. (1961)

BOLT, Bruce Alan, Ph.D., Professor of Seismographic Stations, University of California, Berkeley, U.S.A. (1956 ; P3)

BOOKER, Frederick William, D.Sc., Government Geologist, Geological Survey of N.S.W., Mines Department, Sydney. (1951 ; P1)

BOOTH, Brian Douglas, Ph.D., A58 Telegraph Road, Pymble. (1954)

BOSSON, Geoffrey, M.Sc., Professor of Mathematics, University of New South Wales, Kensington. (1951 ; P2)

BRENNAN, Edward, B.E. (Appl. Geology), C/o B.H.P. Prospecting Party, Torrington, via Deepwater, N.S.W. (1962)

BREYER, Bruno, M.D., Ph.D., Department of Agricultural Chemistry, University of Sydney. (1946 ; P1)

BRIDGES, David Somerset, 19 Mount Pleasant Avenue, Normanhurst. (1952)

*BRIGGS, George Henry, D.Sc., 13 Findlay Avenue, Roseville. (1919 ; P1)

BROWN, Desmond J., D.Sc., Ph.D., Department of Medical Chemistry, Australian National University, Canberra, A.C.T. (1942)

BROWN, Kenneth John, A.S.T.C., A.R.A.C.I., 3 Karda Place, Gymea. (1963)

BROWNE, Ida Alison, D.Sc., 363 Edgecliff Road, Edgecliff. (1935 ; P12 ; **President** 1953)

*BROWNE, William Rowan, D.Sc., F.A.A., 363 Edgecliff Road, Edgecliff. (1913 ; P23 ; **President** 1932)

BRYANT, Raymond Alfred Arthur, M.E., Nuffield Professor of Mechanical Engineering, University of New South Wales, Kensington. (1952)

BUCKLEY, Lindsay Arthur, B.Sc., 9 Eulbertie Avenue, Warrawee. (1940)

BULLEN, Keith Edward, Sc.D., F.R.S., F.A.A., Professor of Applied Mathematics, University of Sydney. (1946 ; P2)

BURG, Raymond Augustine, Senior Analyst, Department of Mines, N.S.W. ; p.r. 17 Titania Street, Randwick. (1960)

BURNS, Bruce Bertram, B.D.S., Dentist, P.O. Box 60, Armidale. (1961)

BUTLAND, Gilbert James, B.A., Ph.D., F.R.G.S., Professor of Geography, University of New England, Armidale. (1961)

CAMERON, John Craig, M.A., B.Sc. (Edin.), 15 Monterey Street, Kogarah. (1957)

CAMPBELL, Ian Gavin Stuart, B.Sc., C/o Barker College, Hornsby. (1955)

*CAREY, Samuel Warren, D.Sc., Professor of Geology, University of Tasmania, Hobart, Tas. (1938 ; P2)

CAVILL, George William Kenneth, Ph.D., D.Sc., Professor of Organic Chemistry, University of New South Wales, Kensington. (1944)

*CHAFFER, Edric Keith, 27 Warrane Road, Roseville. (1954)

CHALMERS, Robert Oliver, Australian Museum, College Street, Sydney. (1933 ; P1)

CHAMBERS, Maxwell Clark, B.Sc., 58 Spencer Street, Killara. (1940)

CHAPPELL, Bruce William, B.Sc., Geology Department, Australian National University, Canberra, A.C.T. (1960 ; P1)

CHRISTIE, Thelma Isabel, B.Sc., Chemistry School, University of New South Wales, Kensington. (1953)

CHURCHWARD, John Gordon, B.Sc.Agr., Ph.D., C/o The Australian Wheat Board, 528 Lonsdale Street, Melbourne, C.1. (1935 ; P2)

CIENSKA, Christine, M.Econ. (Warsaw), Librarian, Sydney Technical College, Ultimo ; p.r. Flat 511, 54 High Street, Kirribilli. (1963)

CLANCY, Brian Edward, M.Sc., C/o Australian Atomic Energy Commission, Lucas Heights. (1957)

COALSTAD, Stanton Ernest, B.Sc., Metallurgical Chemist, 54 Bridge Street, Sydney. (1961)

COHEN, Samuel Bernard, M.Sc., 35 Spencer Road, Killara. (1940)

COLE, Edward Ritchie, B.Sc., Associate Professor of Organic Chemistry, University of New South Wales, Kensington. (1940 ; P2)

COLE, Joyce Marie (Mrs.), B.Sc., 7 Wolsten Avenue, Turramurra. (1940 ; P1)

COLE, Leslie Arthur, 61 Kissing Point Road, Turramurra. (1948)

COLEMAN, Patrick Joseph, Ph.D., Geology Department, University of Western Australia, Nedlands, W.A. (1955)

COLLETT, Gordon, B.Sc., 16 Day Road, Cheltenham. (1940)

CONAGHAN, Hugh Francis, M.Sc., Senior Analyst, Department of Mines, N.S.W. ; p.r. 104 Lancaster Avenue, West Ryde. (1960)

CONOLLY, John Robert, B.Sc. (Syd.), Ph.D. (N.S.W.), Lamont Geological Observatory, Palisades, N.Y., U.S.A. (1963 ; P1)

COOK, Cyril Lloyd, Ph.D., C/o Propulsion Research Laboratories, Box 1424H, G.P.O., Adelaide, S.A. (1948)

*COOMBS, F. A., F.C.S., Bannerman Crescent, Rosebery. (1913 ; P5)

CORBETT, Robert Lorimer, C/o Intaglio Pty. Ltd., Sirius Road, Lane Cove. (1933)

CORTIS-JONES, Beverley, M.Sc., 65 Peacock Street, Seaforth. (1940)

COSS, Paul, B.Sc., 10 Lucia Avenue, St. Ives. (1963)

CRAWFORD, Edwin John, B.E., "Lynwood", Bungalow Avenue, Pymble. (1955)

CRAWFORD, Ian Andrew, Cr. Barker and O'Grady Streets, Havenview, via Burnie, Tas. (1955)

*CRESSWICK, John Arthur, 101 Villiers Street, Rockdale. (1921 ; P1)

CROFT, James Bernard, 24 Judson Road, Normanhurst. (1956)

CROOK, Keith Alan Waterhouse, Ph.D., Geology Department, Australian National University, Canberra, A.C.T. (1954 ; P9)

DAVIES, George Frederick, 57 Eastern Avenue, Kingsford. (1952)

DAVIS, Gwenda Louise, B.Sc., Ph.D., Associate Professor, Department of Botany, University of New England, Armidale. (1961)

DAVIS, Iain Horwood, B.Sc. (Lond.), Department of Geography, University of Queensland, St. Lucia, Brisbane. (1961)

DAY, Arthur Alan, Ph.D., Department of Geology and Geophysics, University of Sydney. (1952)

DENTON, Leslie A., Bunarba Road, Miranda. (1955)

DIVNICH, George, Engineer Agronom. (Yugoslavia), Engineering Analyst, 7 Highland Avenue, Punchbowl. (1960)

DOHERTY, Gregory, B.Sc.(Hons.), C/o Australian Atomic Energy Commission, Lucas Heights. (1963)

*DONEGAN, Henry Arthur James, M.Sc., Chief Analyst, Department of Mines, N.S.W., C/o Mining Museum, George Street North, Sydney. (1928; P1; **President** 1960)

DRAKE, Lawrence Arthur, B.A.(Hons.), B.Sc., Director, Riverview College Observatory, Riverview. (1962; P1)

DRUMMOND, Heather Rutherford, B.Sc., 2 Gerald Avenue, Roseville. (1950)

DULHUNTY, John Allan, D.Sc., Department of Geology and Geophysics, University of Sydney. (1937; P17; **President** 1947)

DURIE, Ethel Beatrix, M.B., Ch.M., Institute of Medical Research, Royal North Shore Hospital, St. Leonards. (1955)

EADE, Ronald Arthur, Ph.D., School of Organic Chemistry, University of New South Wales, Kensington. (1945)

EDGAR, Joyce Enid (Mrs.), B.Sc., 22 Slade Avenue, Lindfield. (1951)

EDGELL, Henry Stewart, Ph.D., Geological Survey of Western Australia, 26 Francis Street, Perth, W.A. (1950)

ELKIN, Adolphus Peter, Ph.D., Emeritus Professor, 15 Norwood Avenue, Lindfield. (1934; P2; **President** 1940)

ELLISON, Dorothy Jean, M.Sc., 45 Victoria Street, Roseville. (1949)

EMMERTON, Henry James, B.Sc., 37 Wangoola Street, East Gordon. (1940)

ENGEL, Brian Adolph, M.Sc., Geology Department, Newcastle University College, Tighe's Hill, 2N. (1961; P1)

*ESDAILE, Edward William, 4 Towers Place, Arncliffe. (1908)

ESSEX, Elizabeth Annette, B.Sc.(Hons.), Physics Department, University of New England, Armidale. (1963)

EVERETT, Frederick A., B.Sc. (Syd.), C/o Jannali Boys' High School, Jannali. (1963)

FALLON, Joseph James, 1 Coolong Road, Vaucluse. (1950)

FAYLE, Rex Dennes Harris, Pharmaceutical Chemist, 141 Jeffrey Street, Armidale. (1961)

FINDLER, Nicholas Victor, B.E.(Hons.), Ph.D., Applied Mathematician, 39 Rembrandt Avenue, Middle Cove. (1962)

FISHER, Robert, B.Sc., 3 Sackville Street, Maroubra. (1940)

FISHER, Stephen, M.D., B.Sc., Director of Clinical Pathology, Kanematsu Memorial Institute, Sydney Hospital. (1962)

FLEISCHMANN, Arnold Walter, Flat 4, 36 Mitchell Street, Bondi. (1956)

FLETCHER, Harold Oswald, M.Sc., The Australian Museum, College Street, Sydney. (1933)

FLETCHER, Neville Horner, B.Sc., M.A., Ph.D., Professor of Physics, University of New England, Armidale. (1961)

FORMAN, Kenn P., C/o 52 Pitt Street, Sydney. (1932)

FRENCH, Oswald Raymond, 78 Hercules Street, Dulwich Hill. (1951)

FRIEND, James Alan, Ph.D., Department of Chemistry, University of Tasmania, Hobart, Tas. (1944; P2)

FURST, Hellmut Friedrich, D.M.D. (Hamburg), 158 Bellevue Road, Bellevue Hill. (1945)

FYNN, Anthony Gerard, B.Sc., Director, Riverview College Observatory, Riverview, N.S.W. (1959)

GALLOWAY, Malcolm Charles, B.Sc., Geologist, 17 Johnson Street, Chatswood. (1960)

GARAN, Teodar, Young Road, Ourimbah. (1952)

GARRETTY, Michael Duhan, D.Sc., "Surrey Lodge", Mitcham Road, Mitcham, Victoria. (1935; P2)

GASCOIGNE, Robert Mortimer, Ph.D., Department of Philosophy, University of New South Wales, Kensington. (1939; P4)

GIBSON, Neville Allan, Ph.D., 103 Bland Street, Ashfield. (1942; P6)

GILES, Edward Thomas, M.Sc., Ph.D., D.I.C., F.R.E.S., Senior Lecturer, Department of Zoology, University of New England. (1961)

*GILL, Stuart Frederic, 45 Neville Street, Marrickville. (1947)

GLASSON, Kenneth Roderick, B.Sc., Ph.D., 70 Beecroft Road, Beecroft. (1948)

GOLDING, Henry George, M.Sc., School of Applied Geology, University of New South Wales, Kensington. (1953; P4)

GOLDSTONE, Charles Lillington, B.Agr.Sc., University of New South Wales, Kensington. (1951)

GORDIJEW, Gurij, Engineer Hydro Geology (Inst. Hydro Meteorology in Moscow, 1936), 41 Abbotsford Road, Homebush. (1962)

GORDON, William Fraser, B.Sc., 10 Warren Road, Double Bay. (1949)

GRAHAME, Mervyn Ernest, B.A., Schoolteacher, 161 Parry Street, Hamilton, N.S.W. (1959)

GRANT, John Narcissus Guerrato, Dip.Eng., 37 Chalayer Street, Rose Bay. (1961)

GRAY, Charles Alexander Menzies, B.E., M.E. (Syd.), Professor of Engineering, Wollongong University College, Wollongong. (1948; P1)

GRAY, Noel Mackintosh, B.Sc., 1 Centenary Avenue, Hunter's Hill. (1952)

GRIFFIN, Russell John, B.Sc., C/o Department of Mines, N.S.W., Sydney. (1952)

GRIFFITH, James Langford, B.A., M.Sc., School of Mathematics, University of New South Wales, Kensington. (1952; P14; **President** 1958)

GRODEN, Charles Mark, M.Sc., School of Mathematics, University of New South Wales, Kensington. (1957; P3)

GUTMANN, Felix, Ph.D., Associate Professor of Physical Chemistry, University of New South Wales, Kensington. (1946; P1)

GUTSCHE, Herbert William, B.Sc., Research Assistant, Geology Department, University of New England, Armidale. (1961)

HALL, Norman Frederick Blake, M.Sc., 16A Wharf Road, Longueville. (1934)

HAMPTON, Edward John William, 1 Hunter Street, Waratah, 2N, N.S.W. (1949)

HANCOCK, Harry Sheffield, M.Sc., 21 Constitution Road, Dulwich Hill. (1955)

HANLON, Frederick Noel, B.Sc., 4 Pearson Avenue, Gordon. (1940 ; P14 ; **President** 1957)

HARPER, Arthur Frederick Alan, M.Sc., National Standards Laboratory, University Grounds, City Road, Chippendale. (1936 ; P1 ; **President** 1959)

HARRIS, Clive Melville, Ph.D., Associate Professor, School of Inorganic Chemistry, University of New South Wales, Kensington. (1948 ; P6)

HARRISON, Ernest John Jasper, B.Sc., C/o N.S.W. Geological Survey. Mines Department, Sydney. (1946)

HAWKINS, Cedric Arthur, B.Sc.Agr., Chemists' Branch, N.S.W. Department of Agriculture, Victoria Road, Rydalmere. (1956 ; P3)

*HAYES, Daphne (Mrs.), B.Sc., 98 Lang Road, Centennial Park. (1943)

HIGGS, Alan Charles, C/o Colonial Sugar Refining Co. Ltd., Building Material Division, 1-7 Bent Street, Sydney. (1945)

HILL, Dorothy, D.Sc., F.A.A., Professor, Department of Geology, University of Queensland, St. Lucia, Brisbane. (1938 ; P6)

*HOGARTH, Julius William, B.Sc., Unit 4, " Hillsmore ", 20 Joubert Street, Hunter's Hill. (1948 ; P6)

HOLM, Thomas John, 524 Wilson Street, Redfern. (1952)

HORNE, Allan Richard, 7 Booralee Street, Botany. (1960)

HOSKINS, Bernard Foster, B.Sc., C/o Chemical Crystallography Laboratory, South Parks Road, Oxford, England. (1959)

HOWE, Bernard Adrian, c/o Exploration Physics, 265 Old Canterbury Road, Dulwich Hill. (1963)

HUMPHRIES, John William, B.Sc., Physicist, National Standards Laboratory, University Grounds, City Road, Chippendale. (1959 ; **President** 1964)

*HYNES, Harold John, D.Sc.Agr., Director, N.S.W. Department of Agriculture, Sydney. (1923 ; P3)

IREDALE, Thomas, D.Sc., 8 Nulla Nulla Street, Turramurra. (1943)

IZSAK, Dennis, 5 Ormond Gardens, Coogee. (1961)

JACKSON, Robert James, M.A. (Q'ld.), M.B., Ch.M. (Syd.), Medical Practitioner, 132 Faulkner Street, Armidale. (1961)

JAEGER, John Conrad, D.Sc., F.A.A., Geophysics Department, Australian National University, Canberra, A.C.T. (1942 ; P1)

JAMIESON, Helen Campbell, 3 Hamilton Street, Coogee. (1951)

JENKINS, Thomas Benjamin Huw, Ph.D., Department of Geology and Geophysics, University of Sydney. (1956)

JONES, James Rhys, 25 Boundary Road, Mortdale. (1959)

JOPLIN, Germaine Anne, D.Sc., Geophysics Department, Australian National University, Canberra, A.C.T. (1935 ; P9)

KEANE, Austin, Ph.D., Professor of Mathematics, Wollongong University College. (1955 ; P4)

KEMP, William Ronald Grant, B.Sc., Physicist, 16 Fig Tree Street, Lane Cove. (1960)

*KENNY, Edward Joseph, 65 Park Avenue, Ashfield. (1924 ; P1)

KIMBLE, Frank Oswald, 31 Coronga Crescent, Killara. (1948)

KIMBLE, Jean Annie, B.Sc., 383 Marrickville Road, Marrickville. (1943)

*KIRCHNER, William John, B.Sc., 18 Lyne Road, Cheltenham. (1920)

KITAMURA, Torrence Edward, B.A.(Hons.), B.Sc.(Agr.), Special Agronomist, N.S.W. Department of Agriculture, Sydney. (1964).

KOCH, Leo E., D.Phil.Habil., School of Applied Geology, University of New South Wales, Kensington. (1948)

KRYSKO v. TRYST, Moiren (Mrs.), School of Applied Geology, University of New South Wales, Kensington. (1959)

LAMBETH, Arthur James, B.Sc., " Talanga ", Picton Road, Douglas Park, N.S.W. (1939 ; P3)

LANDECKER, Kurt, D.Ing. (Berlin), Department of Physics, University of New England. (1961)

LANG, Thomas Arthur, M.C.E., Bechtel Corporation, 537 Market Street, San Francisco 5, California, U.S.A. (1955)

LAWRENCE, Laurence James, Ph.D., Associate Professor, School of Applied Geology, University of New South Wales, Kensington. (1951 ; P3)

LEACH, Stephen Laurence, B.Sc., C/o Taubmans Industries Ltd., P.O. Box 91, Chatswood. (1936)

LEAVER, Gaynor Eiluned (Mrs.), B.Sc. (Wales), F.G.S. (Lond.), 30 Ingalara Avenue, Wahroonga. (1961)

LE FEVRE, Raymond James Wood, D.Sc., F.R.S., F.A.A., Professor and Head of the School of Chemistry, University of Sydney. (1947 ; P2 ; **President** 1961)

LEMBERG, Max Rudolph, D.Phil., F.R.S., F.A.A., Assistant Director, Institute of Medical Research, Royal North Shore Hospital, St. Leonards. (1936 ; P3 ; **President** 1955)

LESLIE, Rupert Thomas, M.A., Ph.D., Statistician, National Standards Laboratory, University Grounds, City Road, Chippendale. (1960)

LEWIS, Philip Ronald, J.P., Design Engineer, 13 River View Road, Woolooware. (1962)

*LIONS, Francis, Ph.D., Department of Chemistry, University of Sydney. (1929 ; P56 ; **President** 1946)

LIONS, Jean Elizabeth (Mrs.), B.Sc., 160 Alt Street, Haberfield. (1940)

LLOYD, James Charles, B.Sc., C/o N.S.W. Geological Survey, Mines Department, Sydney. (1947)

LOCKWOOD, William Hutton, B.Sc., C/o Institute of Medical Research, Royal North Shore Hospital, St. Leonards. (1940 ; P1)

LOVERING, John Francis, Ph.D., Department of Geophysics, Australian National University, Canberra, A.C.T. (1951 ; P3)

LOW, Angus Henry, Ph.D., Department of Applied Mathematics, University of Sydney. (1950 ; P2)

LOWENTHAL, Gerhard, Ph.D., M.Sc., 17 Gnarbo Avenue, Carss Park. (1959)

LYONS, Lawrence Ernest, Ph.D., Professor of Chemistry, University of Queensland, St. Lucia, Brisbane. (1948 ; P2)

MACCOLL, Allan, M.Sc., Department of Chemistry, University College, Gower Street, London, W.C.1, England. (1939 ; P4)

McCARTHY, Frederick David, Dip.Anthr., Principal, Institute of Aboriginal Studies, Box 553, City P.O., Canberra, A.C.T. (1949 ; P1 ; **President** 1956)

McCLYMONT, Gordon Lee, B.V.Sc., Ph.D., Professor of Rural Science, University of New England. (1961)

McCOY, William Kevin, C/o Mr. A. J. McCoy, 4 Hall Avenue, Thornleigh. (1943)

McCULLAGH, Morris Behan, 23 Wallaroy Road, Edgecliff. (1950)

McELROY, Clifford Turner, Ph.D., M.Sc., School of Applied Geology, University of New South Wales, Kensington. (1949 ; P2)

McGREGOR, Gordon Howard, 4 Maple Avenue, Pennant Hills. (1940)

McKAY, Maxwell Herbert, M.A., School of Mathematics, University of New South Wales, Kensington. (1956 ; P1)

McKERN, Howard Hamlet Gordon, M.Sc., Senior Chemist, Museum of Applied Arts and Sciences, Harris Street, Broadway, Sydney. (1943 ; P10 ; **President** 1963)

McMAHON, Barry Keys, B.Sc., 2 Peter Place, Bella Vista, N.S.W. (1961)

McMAHON, Patrick Reginald, Ph.D., Professor of Wool Technology, University of New South Wales, Kensington. (1947)

McNAMARA, Barbara Joyce (Mrs.), M.B., B.S., 167 John Street, Singleton, N.S.W. (1943)

MACKAY, Robin Marie, B.Sc., Department of Geology and Geophysics, University of Sydney. (1962)

MAGEE, Charles Joseph, D.Sc.Agr., Division of Science Services, N.S.W. Department of Agriculture, Victoria Road, Rydalmere. (1947 ; P1 ; **President** 1952)

MALES, Pamela Ann, 13 Gelding Street, Dulwich Hill. (1951)

MARSDEN, Joan Audrey, 203 West Street, Crow's Nest. (1955)

MARSHALL, Charles Edward, D.Sc., Professor of Geology and Geophysics, University of Sydney. (1949 ; P1)

MEARES, Harry John Devenish, 27 Milray Avenue, Wollstonecraft. (1949)

*MELDRUM, Henry John, B.Sc., 116 Sydney Road, Fairlight. (1912)

*MELLOR, David Paver, D.Sc., Professor of Inorganic Chemistry, University of N.S.W., Kensington. (1929 ; P25 ; **President** 1941)

MIDDLEHURST, Jack, M.Sc., C.S.I.R.O., Division of Food Preservation, Delhi Road, North Ryde. (1960)

MILLERSHIP, William, M.Sc., 18 Courallie Avenue, Pymble. (1940)

MINNS, Robert William, Industrial Chemist, C/o O. T. Lempriere & Co. Ltd., Box 117, G.P.O., Sydney. (1963)

MINTY, Edward James, M.Sc., B.Sc., Dip.Ed., 2 Dowel Street, Chatswood. (1951 ; P2)

MORGAN, Jascha Ann, M.Sc., Department of Zoology, University of New England, Armidale. (1961)

MORRIS, Ronald James Huntbatch, M.Sc. (Melb.), Department of Physiology, University of New England, Armidale. (1963)

*MORRISON, Frank Richard, 4 Mona Street, Wahroonga. (1922 ; P34 ; **President** 1950)

MORRISSEY, Matthew John, M.B., B.S., 152 Marsden Street, Parramatta. (1941)

MORT, Francis George Arnot, 29 Preston Avenue, Fivedock. (1934)

MOSHER, Kenneth George, B.Sc., 9 Yirgella Avenue, Killara. (1948)

MOSS, Francis John, M.B., B.S., 37 Avenue Road, Mosman. (1955)

MOYE, Daniel George, B.Sc., Chief Geologist, C/o Snowy Mountains Hydro Electric Authority, Cooma, N.S.W. (1944)

MULHOLLAND, Charles St. John, B.Sc., 5 Garthowen Avenue, Lane Cove. (1946)

*MURPHY, Robert Kenneth, Dr.Ing.Chem., 68 Pindari Avenue, North Mosman. (1915)

MURRAY, Patrick Desmond Fitzgerald, D.Sc., F.A.A., Department of Zoology, University of New England, Armidale. (1950)

NASHAR, Beryl, Ph.D., 23 Morris Street, Mayfield West, 2N, N.S.W. (1946 ; P2)

NAYLOR, George Francis King, Ph.D., Department of Psychology and Philosophy, University of Queensland, St. Lucia, Brisbane. (1930 ; P7)

*NEUHAUS, John William George, 32 Bolton Street, Guildford. (1943)

NEWMAN, Ivor Vickery, Ph.D., Botany Department, University of Sydney. (1932)

NEWMAN, Thomas Montague, Flat 9, " Red Hill Court ", Monaro Crescent, Red Hill, A.C.T. (1962)

NOAKES, Lyndon Charles, B.A., C/o Bureau of Mineral Resources Geology and Geophysics, Canberra, A.C.T. (1945 ; P1)

*NOBLE, Robert Jackson, Ph.D., 32A Middle Harbour Road, Lindfield. (1920 ; P4 ; **President** 1934)

NYHOLM, Ronald Sydney, D.Sc., F.R.S., Professor of Inorganic Chemistry, University College, Gower Street, London, W.C.1, England. (1940 ; P26 ; **President** 1954)

O'FARRELL, Antony Frederick Louis, A.R.C.Sc., B.Sc., Professor of Zoology, University of New England, Armidale. (1961)

OLD, Adrian Noel, B.Sc.Agr., Chemist, N.S.W. Department of Agriculture, Victoria Road, Rydalmere. (1947)

OXENFORD, Reginald Augustus, B.Sc., 75 Alice Street, Grafton. (1950)

PACKHAM, Gordon Howard, Ph.D., Department of Geology and Geophysics, University of Sydney. (1951 ; P4)

*PENFOLD, Arthur Ramon, Flat 516, Baroda Hall, 6A Birtley Place, Elizabeth Bay. (1920 ; P82 ; **President** 1935)

PERRY, Hubert Roy, B.Sc., 74 Woodbine Street, Bowral, 1S, N.S.W. (1948)

PHILLIPS, Marie Elizabeth, Ph.D., Soils Conservation Section, S.M.H.E.A., Cooma, N.S.W. ; p.r. 4 Morella Road, Clifton Gardens. (1938)

PHIPPS, Charles Verling Gayer, Ph.D., Department of Geology and Geophysics, University of Sydney. (1960)

PINWILL, Norman, B.A., The Scots College, Victoria Road, Bellevue Hill. (1946)

PLUMMER, Brian Alfred George, M.A., F.G.S., Department of Geography, University of New England, Armidale. (1961)

POGGENDORFF, Walter Hans George, B.Sc.Agr., Chief, Division of Plant Industry, N.S.W. Department of Agriculture, Victoria Road, Rydalmere. (1949)

POLLARD, John Percival, Dip.App.Chemistry (Swinburne), Mathematician with Australian Atomic Energy Commission; p.r. 25 Nabiac Avenue, Gymea. (1963)

*POWELL, Charles Wilfred Roberts, 1127 Barrenjoey Road, Palm Beach. (1921; P2)

*PRICE, William Lindsay, B.Sc., 107 Spring Street, Killara. (1927)

PRIDDLE, Raymond Arthur, B.E., 7 Rawson Crescent, Pymble. (1956)

PRIESTLEY, John Henry, M.B., B.S., B.Sc., Medical Practitioner, 137 Dangar Street, Armidale. (1961)

PROKHOVNIK, Simon Jacques, B.A., B.Sc., School of Mathematics, University of New South Wales. (1956; P3)

*PROUD, John Seymour, B.E., Finlay Road, Turramurra. (1945)

PUTTOCK, Maurice James, B.Sc.(Eng.), A.Inst.P., Principal Research Officer, C.S.I.R.O., Sydney; p.r. 2 Montreal Avenue, Killara. (1960)

PYLE, John Herbert, B.Sc., Analyst, Mines Department, Sydney. (1958)

*QUODLING, Florrie Mabel, B.Sc., Geology Department, University of Sydney. (1935; P4)

RADE, Janis, M.Sc., Box 28A, 601 St. Kilda Road, Melbourne. (1953; P4)

*RAGGATT, Sir Harold George, Kt., C.B.E., D.Sc., F.A.A., Secretary, Department of National Development, Acton, Canberra. A.C.T. (1922; P8)

RAMM, Eric John, Experimental Officer, Australian Atomic Energy Commission, Lucas Heights, N.S.W. (1959)

*RANCLAUD, Archibald Boscawen Boyd, B.E., 79 Frederick Street, Merewether, N.S.W. (1919; P3)

RAYNER, Jack Maxwell, B.Sc., Director, Bureau of Mineral Resources, Canberra, A.C.T. (1931; P1)

READ, Harold Walter, B.Sc., B.H.P. Prospecting Party, Groote Eylandt, N.T. (1962)

REICHEL, Alex, Ph.D., M.Sc., Department of Applied Mathematics, University of Sydney. (1957; P4)

RIGBY, John Francis, B.Sc. (Melb.), Geology Department, Newcastle University College, Tighe's Hill, 2N, N.S.W. (1963)

RIGGS, Noel Victor, B.Sc. (Adel.), Ph.D. (Cantab.), F.R.A.C.I., A/Professor of Organic Chemistry, University of New England, Armidale. (1961)

RITCHIE, Arthur Sinclair, M.Sc., Senior Lecturer in Geology, Newcastle University College, Tighe's Hill, 2N, N.S.W. (1947; P2)

RITCHIE, Ernest, D.Sc., F.A.A., Chemistry Department, University of Sydney. (1939; P19)

ROBBINS, Elizabeth Marie (Mrs.), M.Sc., Waterloo Road, North Ryde. (1939; P3)

ROBERTS, Herbert Gordon, C/o Bureau of Mineral Resources, Childers Street, Turner, Canberra, A.C.T. (1957)

ROBERTS, John, Ph.D., Bureau of Mineral Resources, Childers Street, Turner, Canberra, A.C.T. (1961; P2)

ROBERTSON, William Humphrey, B.Sc., C/o Sydney Observatory, Sydney. (1949; P20)

ROBINSON, David Hugh, 12 Robert Road, West Pennant Hills. (1951)

ROSENBAUM, Sydney, 5 Eton Road, Lindfield. (1940)

ROSENTHAL-SCHNEIDER, Ilse, Ph.D., 48 Cambridge Avenue, Vaucluse. (1948)

ROSS, Victoria (Mrs.), B.Sc.(Hons.), 26 Gold Street, Blakehurst. (1960)

ROUNTREE, Phyllis Margaret, D.Sc., Royal Prince Alfred Hospital, Sydney. (1945)

ROYLE, Harold George, M.B., B.S. (Syd.), 161 Rusden Street, Armidale. (1961)

RYAN, D. J., School of Anthropology, University of Western Australia, Nedlands, W.A. (1959)

*SCAMMELL, Rupert Boswood, B.Sc., 10 Buena Vista Avenue, Clifton Gardens. (1920)

SCHOLER, Harry Albert Theodore, M.Eng., Civil Engineer, C/o Harbours and Rivers Branch, Public Works Department, N.S.W., cnr. Bridge and Phillip Streets, Sydney. (1960)

SEE, Graeme Thomas, B.Sc., School of Applied Geology, University of New South Wales, Kensington. (1949)

SELBY, Edmond Jacob, Box 175D, G.P.O., Sydney. (1933)

*SHARP, Kenneth Raeburn, B.Sc., C/o S.M.H.E.A., Cooma, N.S.W. (1948)

SHERRARD, Kathleen Margaret (Mrs.), M.Sc., 43 Robertson Road, Centennial Park. (1936; P6)

SHERWOOD, Arthur Alfred, B.Sc.(Eng.), C/o Department of Mechanical Engineering, University of Sydney; p.r. 9 Whitton Road, Chatswood. (1959; P1)

SIMMONS, Lewis Michael, Ph.D., C/o The Scots College, Victoria Road, Bellevue Hill. (1945; P3)

SIMONETT, David Stanley, Ph.D., Assistant Professor of Geography, University of Kansas, Lawrence, Kansas, U.S.A. (1948; P3)

SIMS, Kenneth Patrick, B.Sc., 24 Catherine Street, St. Ives. (1950; P10)

SLADE, George Hermon, B.Sc., C/o W. Hermon Slade & Co. Pty. Ltd., Mandemar Avenue, Homebush. (1933)

SLADE, Milton John, B.Sc., 20 Dobie Street, Grafton. (1952)

SMITH, Ann Ruth (Mrs.), B.Sc., Box 134, P.O. Queenstown, Tasmania. (1959)

SMITH, Glennie Forbes, B.Sc., Box 134, P.O. Queenstown, Tasmania. (1962)

SMITH, Roger Albert Alfred, 62 Budyan Road, Gray's Point. (1960)

SMITH, William Eric, M.Sc. (Syd.), B.Sc. (Oxon.), School of Applied Mathematics, University of New South Wales, Kensington. (1963)

SMITH-WHITE, William Broderick, M.A., Associate Professor, Department of Mathematics, University of Sydney. (1947 ; P3 ; **President** 1962)

SOMERVILLE, Jack Murielle, M.A., D.Sc., Professor of Physics, University of New England, Armidale. (1959)

SOURRY, Charles, Laboratory Manager, Zoology Department, University of New England, Armidale. (1961)

*SOUTHEE, Ethelbert Ambrook, O.B.E., M.A., Trelawney Street, Eastwood. (1919)

SPITZER, Hans, Dr.Phil. (Vienna), Senior Research Chemist, Monsanto Chemicals (Aust.) Ltd., Rozelle ; p.r. 35 Redan Street, Mosman. (1961)

STANTON, Richard Limon, Ph.D., Associate Professor, Geology Department, University of New England, Armidale. (1949 ; P2)

STAPLEDON, David Hiley, B.Sc., 61 Francis Street, Brighton, South Australia. (1954)

*STEPHENS, Frederick G. N., M.B., Ch.M., 133 Edinburgh Road, Castlecrag. (1914)

STEPHENS, James Norrington, M.A. (Cantab.), University of New South Wales, Broken Hill Division, Argent Street, Broken Hill. (1959)

STEVENS, Eric Leslie, B.Sc., Lot 17, Chaseling Avenue, Springwood. (1963)

STEVENS, Neville Cecil, Ph.D., Geology Department, University of Queensland, Brisbane. (1948 ; P5)

STOCK, Alexander, D.Phil., Ph.D., Associate Professor of Zoology, University of New England, Armidale. (1961)

STOKES, Robert Harold, Ph.D., D.Sc., F.A.A., 45 Garibaldi Street, Armidale. (1961)

*STONE, Walter George, 26 Rosslyn Street, Bellevue Hill. (1916 ; P1)

STRUSZ, Desmond Leslie, Ph.D., B.Sc., Department of Geology, University College of Townsville, Pimlico, Townsville. (1960 ; P1)

STUNTZ, John, B.Sc., 511 Burwood Road, Belmore. (1951)

*SUTHERLAND, George Fife, A.R.C.Sc., 47 Clanwilliam Street, Chatswood. (1919)

SWANSON, Thomas Baikie, M.Sc., C/o Technical Service Department, ICIANZ, Box 1911, G.P.O., Melbourne. (1941 ; P2)

SWINBOURNE Ellice Simmons, Ph.D., 69 Peacock Street, Seaforth. (1948)

*TAYLOR, Brigadier Harold B., M.C., D.Sc., 12 Wood Street, Manly. (1915 ; P3)

TAYLOR Nathaniel Wesley, M.Sc. (Syd.), Ph.D. (N.E.), Department of Mathematics, University of New England, Armidale. (1961)

THEW, Raymond Farly, 88 Braeside Street, Wahroonga. (1955)

THOMAS, Penrhyn Francis, Suite 22, 3rd Floor, 29 Market Street, Sydney. (1952)

THOMSON, David John, B.Sc., Geologist, 61 The Bulwark, Castlecrag. (1956)

THOMSON, Vivian Endel, B.Sc., C/o S.M.H.E.A., Geological Laboratory, Scientific Services Division, Cooma North, N.S.W. (1960)

THWAITE, Eric Graham, B.Sc., 8 Allars Street, West Ryde. (1962)

THURSTAN, Arthur Wyngate, A.S.T.C., A.R.A.C.I., Metallurgist, 99 Stoney Creek Road, Beverly Hills. (1964)

TICHAUER, Erwin R., D.Sc.(Tech.), Dipl.Ing., Department of Industrial Engineering, Texas College, Lubbock, Texas, U.S.A. (1960)

TOMPKINS, Denis Keith, Ph.D., M.Sc., C/o Department of Geology and Geophysics, University of Sydney. (1954 ; P1)

TOW, Aubrey James, M.Sc., C/o Community Hospital, Canberra, A.C.T. (1940)

TREBECK, Prosper Charles Brian, 54 Great North Road, Fivedock. (1949)

UNGAR, Andrew, Dr.Ing., 6 Ashley Grove, Gordon. (1952)

VALLANCE, Thomas George, Ph.D., Department of Geology and Geophysics, University of Sydney. (1949 ; P1)

VAN DIJK, Dirk Cornelius, D.Sc.Agr., 2 Lobelia Street, O'Connor, Canberra, A.C.T. (1958)

VEEVERS, John James, Ph.D., C/o Bureau of Mineral Resources, Canberra, A.C.T. (1953)

VERNON, Ronald Holden, M.Sc., Department of Geology and Geophysics, University of Sydney. (1958 ; P1)

VICKERY, Joyce Winifred, M.B.E., D.Sc., 17 The Promenade, Cheltenham. (1935)

VOISEY, Alan Heywood, D.Sc., Professor of Geology and Geography, University of New England, Armidale. (1933 ; P11)

*VONWILLER, Oscar U., B.Sc., Emeritus Professor, Rathkells, Kangaroo Valley, N.S.W. (1903 ; P10 ; **President** 1940)

WALKER, Donald Francis, 13 Beauchamp Avenue, Chatswood. (1948)

WALKER, Patrick Hilton, M.Sc.Agr., Research Officer, C.S.I.R.O., Division of Soils, Canberra, A.C.T. (1956 ; P3)

*WALKOM, Arthur Bache, D.Sc., 5/521 Pacific Highway, Killara. (1919 and previous membership 1910–1913 ; P2 ; **President** 1943)

WARD, Judith (Mrs.), B.Sc., 50 Bellevue Parade, New Town, Hobart, Tasmania. (1948)

*WARDLAW, Hy. Sloane Halcro, D.Sc., 71 McIntosh Street, Gordon. (1913 ; P5 ; **President** 1939)

*WATERHOUSE, Lionel Lawry, B.E., 42 Archer Street, Chatswood. (1919 ; P1)

*WATERHOUSE, Walter L., C.M.G., M.C., D.Sc.Agr., F.A.A., 30 Chelmsford Avenue, Lindfield. (1919; P7 ; **President** 1937)

*WATT, Sir Robert Dickie, M.A., Emeritus Professor, 5 Gladswood Gardens, Double Bay. (1911 ; P1 ; **President** 1925)

WATTON, Edward Charlton, B.Sc.(Hons.), A.S.T.C., 2/116 Maroubra Road, Maroubra. (1963)

*WATTS, Arthur Spencer, " Araboonoo ", Glebe Street, Randwick. (1921)

WENHAM, Russell George, B.Sc., B.E., 17 Fortescue Street, Bexley North. (1960)

WEST, Norman William, B.Sc., C/o Department of Main Roads, Sydney. (1954)

WESTHEIMER, Gerald, Ph.D., University of California, School of Optometry, Berkeley 4, California, U.S.A. (1949)

WHITLEY, Alice, Ph.D., 39 Belmore Road, Burwood. (1951)

WHITLEY, Gilbert Percy, F.R.Z.S., Curator of Fishes, Australian Museum, College Street, Sydney. (1963)

WHITWORTH, Horace Francis, M.Sc., C/o Mining Museum, George Street North, Sydney. (1951 ; P4)

WILKINS, Coleridge Anthony, Ph.D., M.Sc., Mathematics Department, Auckland University, Auckland, N.Z. (1960 ; P1)

WILKINSON, John Frederick George, M.Sc. (Q'land), Ph.D. (Cantab.), A/Professor of Geology, University of New England, Armidale. (1961)

WILLIAMS, Benjamin, 12 Cooke Way, Epping. (1949)

WILLIAMSON, William Harold, M.Sc., 6 Hughes Avenue, Ermington. (1949)

WILSON, Peter Robert, Ph.D., B.A., M.Sc., Lecturer in Applied, Mathematics, University of Sydney. (1959)

WOOD, Clive Charles, Ph.D., B.Sc., 60A Pleasant Road, East Hawthorn, Victoria. (1954)

WOOD, Harley Weston, D.Sc., M.Sc., Government Astronomer, Sydney Observatory, Sydney. (1936; P14 ; **President** 1949)

WRIGHT, Anthony James, B.Sc., Department of Geology and Geophysics, University of Sydney. (1961)

WYLIE, Russell George, Ph.D., M.Sc., Physicist, 11 Church Street, Randwick. (1960)

WYNN, Desmond Watkin, B.Sc., C/o Mines Department, Sydney. (1952)

YATES, Harold, M.Sc. (Syd.), 102 Eyre Street, Ballarat, Victoria. (1962)

YEATES, Neil Tolmie McRae, D.Sc.Agr. (Q'land), Ph.D. (Cantab.), A/Professor of Livestock Husbandry, University of New England, Armidale. (1961)

Associates

BARNET, Michael Terence, 37 Queen Street, Revesby. (1961)

BURNS, Susan Mary (Mrs.), P.O. Box 60, Armidale. (1961)

CRUIKSHANK, Bruce Ian, 16 Arthur Street, Punchbowl. (1961)

DENTON, Norma (Mrs.), Bunarba Road, Miranda. (1959)

DONEGAN, Elizabeth (Mrs.), 18 Hillview Street, Sans Souci. (1956)

GRIFFITH, Elsie A. (Mrs.), 9 Kanoona Street, Caringbah. (1956)

LEAVER, Harry, B.A., B.Sc., M.B., Ch.M., M.R.C.O.G., F.G.S., 30 Ingalara Avenue, Wahroonga. (1962)

LE FEVRE, Catherine Gunn, D.Sc. (Lond.), 6 Aubrey Road, Northbridge. (1961)

McCLYMONT, Vivienne Cathryn, B.Sc., Handel Street, Armidale. (1961)

MORGAN, James Albert, 35A Robertson Road, Centennial Park. (1961)

ROSENTHAL, Hans Samuel Arthur, Dr.Ing. (Berlin), Consulting Engineer, 48 Cambridge Avenue, Vaucluse. (1961)

SHERWOOD, Joan (Mrs.), 9 Whitton Road, Chatswood. (1962)

STANTON, Alison Amalie (Mrs.), B.A., 35 Faulkner Street, Armidale. (1961)

STOKES, Jean Mary (Mrs.), M.Sc., 45 Garibaldi Street, Armidale. (1961)

Obituary, 1962-63

Adolph BOLLIGER (1933)
Anthony DADOUR (1940)
Francis F. P. DWYER (1934)
Burnett MANDER-JONES (1960)

Obituary, 1963-64

Richard C. L. BOSWORTH (1939)
Leo Arthur COTTON (1909)
Franch LEECHMAN (1957)
Harvey SUTTON (1920)
Thomas Griffith TAYLOR (1954,previous membership 1921–28)

Medals, Memorial Lectureships and Prizes awarded by The Society

The James Cook Medal

A bronze medal awarded for outstanding contributions to science and human welfare in and for the Southern Hemisphere.

1947 J. C. Smuts (South Africa)
1948 B. A. Houssay (Argentina)
1950 Sir N. H. Fairley (U.K.)
1951 N. McA. Gregg (Australia)
1952 W. L. Waterhouse (Australia)
1953 Sir D. Rivett (Australia)
1954 Sir F. M. Burnet (Australia)
1955 A. P. Elkin (Australia)
1956 Sir I. Clunies Ross (Australia)
1959 A. Schweitzer (Fr. Eq. Africa)
1961 Sir J. C. Eccles (Australia)

The Walter Burfitt Prize

A bronze medal and money prize of £75 awarded at intervals of three years to the worker in pure and applied science, resident in Australia or New Zealand, whose papers and other contributions published during the preceding six years are deemed of the highest scientific merit, account being taken only of investigations described for the first time, and carried out by the author mainly in those Dominions. Established as a result of generous gifts to the Society of Dr. and Mrs. W. F. Burfitt.

1929 N. D. Royle (Medicine)
1932 C. H. Kellaway (Medicine)
1935 V. A. Bailey (Physics)
1938 F. M. Burnet (Medicine)
1941 F. W. Whitehouse (Geology)
1944 H. L. Kesteven (Medicine)
1947 J. C. Jaeger (Mathematics)
1950 D. F. Martyn (Ionospheric Physics)
1953 K. E. Bullen (Geophysics)
1956 J. C. Eccles (Medicine)
1959 F. J. Fenner (Medicine)
1962 M. F. Glaessner (Palaeontology)

The Clarke Medal

Awarded from time to time for distinguished work in the Natural Sciences done in or on the Australian Commonwealth and its territories ; the person to whom the award is made may be resident in the Australian Commonwealth or its territories or elsewhere. Established by the Society soon after the death of the Rev. W. B. Clarke in appreciation of his character and services " as a learned colonist, a faithful minister of religion, and an eminent scientific man ".

The recipients from 1878 to 1929 were given in this Journal, vol. 89, p. xv, 1955.

1930 L. Keith Ward (Geology)
1931 R. J. Tillyard (Entomology)
1932 F. Chapman (Palaeontology)
1933 W. G. Woolnough (Geology)
1934 E. S. Simpson (Mineralogy)
1935 G. W. Card (Geology)
1936 Sir Douglas Mawson (Geology)
1937 J. T. Jutson (Geology)
1938 H. C. Richards (Geology)
1939 C. A. Sussmilch (Geology)
1941 F. Wood Jones (Zoology)
1942 W. R. Browne (Geology)
1943 W. L. Waterhouse (Botany)
1944 W. E. Agar (Zoology)
1945 W. N. Benson (Geology)
1946 J. M. Black (Botany)
1947 H. L. Clark (Botany)
1948 A. B. Walkom (Palaeobotany)
1949 Rev. H. M. R. Rupp (Botany)
1950 I. M. Mackerras (Entomology)
1951 F. L. Stillwell (Geology)
1952 J. G. Wood (Botany)
1953 A. J. Nicholson (Entomology)
1954 E. de C. Clarke (Geology)
1955 R. N. Robertson (Botany)
1956 O. W. Tiegs (Zoology)
1957 Irene Crespin (Geology)
1958 T. G. B. Osborn (Botany)
1959 T. Iredale (Zoology)
1960 A. B. Edwards (Geology)
1961 C. A. Gardner (Botany)
1962 H. Waring (Zoology)
1963 Germaine A. Joplin (Geology)
1964 Joyce W. Vickery (Botany)

The Society's Medal

A bronze medal awarded from 1884 until 1896 for published papers. The Award was revived in 1943 for scientific contributions and services to the Society.

1884 W. E. Abbott
1886 S. H. Cox
1887 J. Seaver
1888 Rev. J. E. Tenison-Woods
1889 T. Whitelegge
Rev. J. Mathew
1891 Rev. J. Milne Curran
1892 A. G. Hamilton
1894 J. V. De Coque
R. H. Mathews
1895 C. J. Martin
1896 Rev. J. Milne Curran
1943 E. Cheel (Botany)
1948 W. L. Waterhouse (Agriculture)
1949 A. P. Elkin (Anthropology)
1950 O. U. Vonwiller (Physics)
1951 A. R. Penfold (Applied Chemistry)
1953 A. B. Walkom (Palaeobotany)
1954 D. P. Mellor (Chemistry)
1955 W. G. Woolnough (Geology)
1956 W. R. Browne (Geology)
1957 R. C. L. Bosworth (Physical Chemistry)
1958 F. R. Morrison (Applied Chemistry)
1959 Ida A. Browne (Geology)
1960 T. Griffith Taylor (Geography)
1961 A. Bolliger (Biochemistry)
1962 Harley Wood (Astronomy)
1963 R. S. Nyholm (Chemistry)

The Edgeworth David Medal

A bronze medal awarded to Australian research workers under the age of thirty-five years for work done mainly in Australia or its territories, or contributing to the advancement of Australian science.

1948 R. G. Giovanelli (Astrophysics)
E. Ritchie (Organic Chemistry)
1949 T. B. Kiely (Plant Pathology)
1950 R. M. Berndt (Anthropology)
Catherine H. Berndt (Anthropology)
1951 J. G. Bolton (Radio Astronomy)
1952 A. B. Wardrop (Botany)
1954 E. S. Barnes (Mathematics)
1955 H. B. S. Womersley (Botany)
1957 J. M. Cowley (Chemical Physics)
J. P. Wild (Radio Astronomy)
1958 P. I. Korner (Physiology)
1960 R. D. Brown (Chemistry)
1961 R. O. Slatyer
1962 R. F. Isbell (Soil Science)
1963 N. H. Fletcher (Physics)

Clarke Memorial Lectureship

The lectureship is awarded for the purpose of the advancement of Geology. The practice of publishing the lectures in the Journal began in 1936.

1903 T. W. E. David
1906 E. W. Skeats (two lectures)
1907 T. W. E. David (two lectures)
W. G. Woolnough
E. F. Pittman
W. S. Dun
1918 R. J. A. Berry
1919 T. W. E. David
1936 W. G. Woolnough
1937 H. C. Richards
1938 C. T. Madigan
1939 Sir John S. Flett
1940 E. J. Kenny
1941 C. A. Sussmilch
1942 E. C. Andrews
1943 H. G. Raggatt
1944 W. H. Bryan
1945 E. S. Hills
1946 L. A. Cotton
1947 H. S. Summers
1948 Sir Douglas Mawson
1949 W. R. Browne
1950 F. W. Whitehouse
1951 A. B. Edwards
1953 M. F. Glaessner
1955 R. O. Chalmers
1957 A. H. Voisey
1959 D. E. Thomas
1961 J. A. Dulhunty

Liversidge Research Lectureship

The lectureship is awarded at intervals of two years for the purpose of encouragement of research in Chemistry. It was established under the terms of a bequest to the Society by Professor Archibald Liversidge. The lectures are published in the Journal.

1931 H. Hey
1933 W. J. Young
1940 G. J. Burrows
1942 J. S. Anderson
1944 F. P. Bowden
1946 L. H. Briggs
1948 I. Lauder
1950 Hedley R. Marston
1952 A. L. G. Rees
1954 M. R. Lemberg
1956 G. M. Badger
1958 A. D. Wadsley
1960 R. J. W. Le Fevre
1962 D. O. Jordan

Pollock Memorial Lectureship

Sponsored by the University of Sydney and the Royal Society of New South Wales in memory of Professor J. A. Pollock.

1949 T. M. Cherry
1952 H. S. W. Massey
1955 R. v. d. R. Woolley
1959 Sir Harold Jeffreys
1962 F. Hoyle

The Archibald D. Olle Prize

Awarded from time to time at the discretion of the Council to the member of the Society who has submitted the best paper in any year. Established under the terms of a bequest by Mrs. A. D. Olle.

1956 R. L. Stanton
1958 Alex Reichel
1959 G. Bosson
1960 H. G. Golding

The Society's Money Prize

A prize of £25 awarded for published papers (awarded in 1882 only).

1882 J. Fraser and A. Ross

Annual Report of the New England Branch of The Royal Society of New South Wales, 1963-64

Officers for the year were :

Chairman : J. H. Priestley.

Secretary-Treasurer : R. L. Stanton.

Committee Members : P. D. F. Murray, R. H. Stokes, N. H. Fletcher, N. W. Taylor, B. A. G. Plummer.

Six meetings were held, as follows :

16th April, 1963 : Mr. Keith Alder, Director Atomic Energy Establishment, Lucas Heights, on " The Lucas Heights installation ".

7th June, 1963 : Dr. A. C. Crombie, Reader in History and Philosophy of Science, Oxford, on " The relevance of the Middle Ages to the scientific movement ".

25th June, 1963 : Dr. A. E. Ringwood, Professorial Fellow in Geophysics, Australian National University, on " The internal constitution of the earth—some recent advances ".

26th September, 1963 : Professor C. A. Keele, Professor of Pharmacology and Therapeutics, Middlesex Hospital Medical School, University of London, on " Pain ".

15th November, 1963 : Dr. E. K. Bigg, Senior Principal Research Officer, Radiophysics Division, C.S.I.R.O., on " Effects of the moon on terrestrial events ".

17th March, 1964 : Professor F. H. T. Rhodes, Department of Geology, University College of Swansea, on " The evolution of life ".

Section of Geology

CHAIRMAN : MRS. K. M. SHERRARD, M.Sc. HON. SECRETARY : D. S. BRIDGES.

Abstract of Proceedings, 1963

Five meetings were held during the year, with an average attendance of 14 members and visitors.

MARCH 15th (*Annual Meeting*). Election of office-bearers :—Chairman : (Mrs.) K. M. Sherrard ; Hon. Secretary : D. S. Bridges.

Business : Symposium on " Spilites ", speakers being Dr. T. G. Vallance and Dr. W. R. Browne.

Abstracts :

Dr. T. G. Vallance : " From spilite, as originally defined (by Brongniart, *ca.* 1815), two traditions are derived—neither now close to the original. The first is that still found in parts of Europe where spilite is recognized as a fine-grained non-porphyritic basalt. The other view, widely propagated in British literature, is due to Dewey and Flett. They claimed that spilites were basic igneous rocks containing albite as the typical felspar and bearing notably higher soda contents than normal basalts. Dewey and Flett further believed that the spilites were members of a soda-rich magmatic suite and that the albite of these rocks was commonly secondary after a primary calcic plagioclase.

Bulking of analyses of spilitic lavas indicates composition of normal basalts (tholeiite or olivine-basalt) plus water. The high soda contents of spilites quoted in the literature are illusory, being based on imperfect sampling. As a rule, only the ' fresh-looking ' cores have been analysed.

The mineral adjustments observed in spilites may result from deuteric or late-magmatic activity, from deep diagenesis, or from low-grade metamorphism, There is probably no unique origin for these rocks which are most reasonably to be regarded as basalts which have undergone redistribution of components at low/moderate temperatures in the presence of excess H_2O (and sometimes CO_2)."

Dr. W. R. Browne : Dr. Browne disclaimed any special knowledge of spilites, but pointed out that over the years he had come in contact with volcanic rocks of many geological ages, basic and acid, submarine and terrestrial, which showed chemical, mineralogical and other characteristics of the so-called spilitic suite. These, however, in their unaltered condition belonged to calcic, latitic and alkaline types, and thus considerable doubt was cast on the existence of a distinctive spilitic suite.

MAY 17th : Address by Miss H. R. Drummond, " Observations in Iceland ".

Miss Drummond summarised the stratigraphy and lithology of Iceland. The entire island is composed only of Tertiary and Recent rocks which consist of two main types—(*a*) volcanics, mainly basalts and pyroclastics, but with rhyolites occurring in places ; and (*b*) glacial and fluvioglacial, including tillites, breccias, conglomerates and outwash gravels. The volcanics are of two ages—pre-Pleistocene and Pleistocene-Recent. Active volcanoes occur, as well as many centres of geyser and fumarole activity. A feature of the tectonic geology of the island is the presence in many areas of pronounced and repeated faulting of the block-and-graben type, and this has had a most definite effect in the production of the present-day topography and in the locations of the present thermal areas. Some reference was made to the permanent ice-sheets which (perhaps surprisingly) cover only a small percentage of the area of the island. By means of some excellent colour slides, Miss Drummond exhibited and explained many aspects of Icelandic architecture, scenery and social life.

JULY 19th : The meeting passed a motion expressing regret at the death of Professor L. A. Cotton, Emeritus Professor of Geology, University of Sydney.

Note and Exhibit : Mr. H. G. Golding noted the occurrence at several locations within the Tumut-Coolac ultra-mafic belt of serpentinites containing disseminated native nickel-iron. Sawn specimens showing numerous megascopically visible particles of the metal were exhibited.

Address by Dr. D. F. Branagan : " Australian Geology before Clarke."

Abstract : " Australian geology had its beginnings in the observations of early explorers and in the search for natural materials.

Three separate groups contributed to our early knowledge : (*a*) the British, (*b*) the French, (*c*) the Europeans and Americans. Among the English two groups can be recognised : (*a*) the practical workers (explorers and miners), and (*b*) the academic workers. Labillardiere, Flinders, Sturt, P. King, Mitchell, Robt. Brown, Fitton, Von Buch, Busby, Platt, Humphreys, Wilton, Lhotsky and Menge were among those who contributed. Our information about these workers is still fragmentary. The geological knowledge obtained was also fragmentary and uncoordinated until Clarke's work began to follow the stratigraphic principles introduced in Europe by Smith and others."

SEPTEMBER 20th : In the absence (overseas) of the Chairman (Mrs. Sherrard), Dr. T. G. Vallance was elected Acting Chairman.

Abstract : Dr. L. E. Koch presented an abstract from a lecture entitled " Geology and Integrated Science ". Dr. Koch referred to the method of " concept structures " and recommended its use in order to facilitate a systematic approach to the complex problems connected with the integration of High School Certificate Science as prescribed by the new syllabus for New South Wales schools.

Notes and Exhibits : Dr. T. G. Vallance reported the probable occurrence of a small volcanic neck of the Hornsby type situated under Bowen Ave., West Turramurra. The occurrence is apparently in situ, and specimens from the area were submitted for examination.

Dr. Ida Browne mentioned the possibility of a similar neck being located at Muogomarra, between Cowan and the Hawkesbury River.

Address by Dr. R. Curtis : " The Geology of Grahamland, West Antarctica."

Abstract: Dr. Curtis described the petrography of the Graham coast and offshore islands. A small succession of siltstones, shales and felspathic greywackes have been correlated with the late Palaeozoic Trinity Peninsula Series and have suffered pre-Jurassic low grade metamorphism. Upper Jurassic volcanics have a minimum thickness of 5000 feet, comprised of approximately 1000 feet of andesite lavas overlain by 4000 feet of pyroclastics.

The initial phase of gabbro intrusion of the Andean Intrusive Suite was followed by successive intrusions of granodiorite magma. The early intrusions of granodiorite magma incorporated large quantities of gabbroic material at depth, which resulted in their basification to a hybrid magma of dioritic composition. Basification had been completed before the magma attained its present level. Successive intrusions were progressively less modified, and the trend of intrusion diorite-tonalite-granodiorite is one of decreasing contamination. The granites and granophyres are thought to represent crystallisation-differentiation products of the granodiorite magma. The present configuration of Grahamland is possibly due to large-scale faults trending parallel to the present axis, and which developed in Pliocene times.

NOVEMBER 15th: (Acting Chairman: Mr. H. G. Golding.) The meeting passed a motion expressing regret at the death of Professor Griffith Taylor, Emeritus Professor of Geography, Universities of Sydney, Chicago and Toronto.

Note and Exhibit: Mr. H. G. Golding referred to occurrences in the northern end of the Gundagai-Coolac serpentine belt of variations in rock-type shown by zonation within the mass, and also to the occurrence of chromite located one mile north of the Murrumbidgee River near Coolac. Specimens relevant to these occurrences were exhibited.

Address by Dr. L. E. Koch: "Touchstone (Lydite), its use through the history of precious metals, and its occurrence in Australia."

Abstract: "The use of the touchstone (Lydianstone=black chert) for the determination by the 'streak test' of the fine content of gold alloys is one of the oldest technological and micro-analytical discoveries of ancient man (700 B.C. or earlier). The colour and reflectivity of the streak of a given gold alloy of unknown composition are visually compared with streaks made by means of 'needles' prepared from alloys of known gold-silver or gold-copper content. After treatment with strong nitric acid for the removal of gold and copper, the new 'spongy' streaks are again compared for similarity or dissimilarity. Pebbles of black siliceous chert are easily obtained from gravels (1″ to 2″) of rivers in New South Wales flowing through the outcrop belt of Palaeozoic rocks (Upper Silurian, Devonian), e.g. Jenolan Creek, Belubula, Wollondilly, Nepean, etc. rivers."

D. S. Bridges,
Hon. Secretary,
Section of Geology.

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NOTICE

The Royal Society of New South Wales originated in 1821 as the "Philosophical Society of Australasia"; after an interval of inactivity it was resuscitated in 1850 under the name of the "Australian Philosophical Society", by which title it was known until 1856, when the name was changed to the "Philosophical Society of New South Wales". In 1866, by the sanction of Her Most Gracious Majesty Queen Victoria, the Society assumed its present title, and was incorporated by Act of Parliament of New South Wales in 1881.

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A Note on the Stratigraphy of the Devonian Garra Beds of New South Wales. *D. L. Strusz* 85

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Volatile Oils and Plant Taxonomy*

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Abstract—Attempts to utilize the chemical compositions of volatile oils in taxonomy are reviewed. Attention is drawn to the weaknesses in earlier work and some guiding principles to be observed in future work in this field are suggested. Although many promising leads have so far appeared, it is considered that both chemical and botanical data are still too insufficient to enable any conclusions to be drawn.

I

The mid-twentieth century scene in organic chemistry shows a strong interest in what Czapek has conveniently referred to as "secondary plant substances", as distinct from such "primary" plant substances as cellulose and proteins. These secondary plant products—alkaloids, glycosides, flavones, gums, resins, waxes and so on—have provided many interesting problems in the elucidation of molecular structure and stereochemistry, and have brought to light many novel and useful substances. As a natural extension to these studies, there has followed enquiry into biosynthetic mechanisms operative within plants, into speculation on the function of these substances in the plant economy, and finally, as to whether they have taxonomic significance, and it is this last-mentioned enquiry which will concern us here. Although chemotaxonomy has been the subject of two recent monographs (Alston and Turner, 1963; Swain, 1963), neither of these works contains a chapter devoted to essential oils considered as a phytochemical category, and the present paper is therefore supplementary to these volumes, both in dealing with this aspect of the topic, as well as in calling attention to more recent data and thought not available in the works just cited. This omission will doubtless be rectified in the work of Hegnauer (1962–) now appearing.

The examination of the possible value of chemistry to plant taxonomy now dates back some considerable time: indeed, early in the 19th century it was observed that certain families displayed a high frequency of occurrence of certain chemical classes — alkaloids in Solanaceae, oleo-resins in Pinaceae, and so on. This paper deals specifically with volatile or essential oils, and here again, in this special case of a phytochemical product, it was early observed that the occurrence of volatile oils was not completely random, but characterized certain families such as Labiateae, Rutaceae, and Myrtaceae. Taking these general observations a step further, chemists noted that, as a result of consideration of the various compounds present in volatile oils, there existed the possibility of a relation between oil composition and the systematic position assigned to the plant. One or two examples will suffice to illustrate this kind of indication.

Baker and Smith (1910) observed in the oil steam-distilled from the foliage of *Phyllocladus rhomboidalis* Rich. (Podocarpaceae) the presence of a crystalline diterpene, $C_{20}H_{32}$, named by them phyllocladene (I). Subsequent workers, particularly in New Zealand, reported the presence of phyllocladene or its isomer *iso*phyllocladene (II) in three other species of *Phyllocladus*; and further, that these diterpenes are of frequent occurrence in the leaf oils of *Podocarpus* and *Dacrydium* (also Podocarpaceae), and they have been identified in such related genera as *Araucaria* (Araucariaceae), *Cupressus* and *Libocedrus* (Cupressaceae), *Sciadopitys* (Sciadopityaceae), and *Cryptomeria* (Taxodiaceae) (cf. Aplin, Cambie and Rutledge, 1963). Both phyllocladene and *iso*phyllocladene are unknown in the angiosperms. Again, consider the case of ascaridole (III). This is a most unusual and distinctive compound, being a monoterpene peroxide. It is an explosive liquid and is altogether a substance not to be expected in nature; nevertheless it is found in large percentages in the volatile oil of not only *Chenopodium ambrosioides* var. *anthelminticum* but is present also in the oils of other *Chenopodium* species such as *C. hircinum*.

Following such leads as these, investigators have studied volatile oil compositions from this viewpoint, and some have presented their

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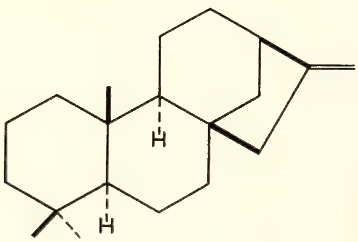
ideas on the part which chemistry might play in plant classification, and even how it might be applied in phylogeny. Several of these attempts will be briefly examined.

One of the early corpora of work in this field is that of Baker and Smith, who presented their views in two monographs, one on *Eucalyptus* (1920), the other on Australian gymnosperms (1910). Setting aside for reasons of space the work on the gymnosperms, their views on *Eucalyptus* may be summarized as follows: (1) Within the limits of variation typical of living organisms, they regarded the oil composition of a species as constant. (2) They regarded oil composition within the genus as susceptible of classification into major chemical groups. Their first group, for example, comprised those oils characterized by the presence of much α-pinene, the absence of α-phellandrene, with 1,8-cineole present in not more than a few per cent. (3) They assumed *Angophora* to be the older genus, and having adduced evidence that *Angophora* oils resembled closely the "pinene group" of *Eucalyptus* oils, they perceived in this a chemical link between *Angophora* and the more primitive eucalypts such as the "bloodwoods" (Series Corymbosae and Corymbosae-peltatae of Blakely, 1955), all species of which examined by them having been found to yield "pinene oils". (4) They claimed a relationship between oil compositions and leaf-venation; maintaining that pinene oils came from species whose leaves showed transverse parallel venation, the intra-marginal vein close to the margin; whilst as phellandrene contents rose, the angles made by the veins with the mid-rib diminished and the intramarginal vein tended to become removed from the margin. With these observations as a starting-point, they postulated an evolutionary pathway in *Eucalyptus*, showing descent from *Angophora*, and how *Eucalyptus* species may have evolved from the more primitive species such as *E. calophylla*.



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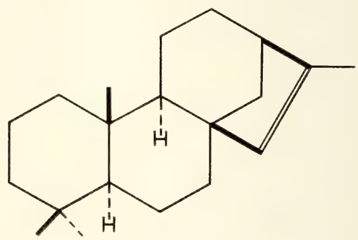

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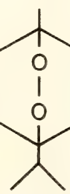


III

A second large body of work published in this field is that of Fujita (1951 and subsequent papers), whose monograph sets forth his views on plant classification based on essential oil compositions. Unlike Baker and Smith, who personally accumulated both field and laboratory data on a few genera only, Fujita has theorized not only his own data (e.g. on *Orthodon*), but accepting uncritically published chemical and taxonomic data (much of it now known to be incomplete or erroneous), has erected on this basis chemical classifications and phylogenies of a large number of genera.

A third work of some magnitude is that of Mirov in *Pinus* (1961). His monograph merits attention for four reasons. Firstly, although much of the work was carried out prior to the advent of gas chromatography, the chemical work is modern and reliable as far as it goes. Secondly, Mirov was at pains to collect botanically authentic material, and was aware of the biological considerations (e.g. hybridism) affecting phytochemical work. Thirdly, he has reported on the compositions of the volatile oils from the oleo-resins of an entire genus. Fourthly, unlike some of the earlier authors, he has preferred to review his data rather than to use them as a basis for elaborate theories.

Such, then, are some examples of the collection of phytochemical data on volatile oils having

as its objective the determination of relationship to taxonomy. Much of the earlier work, however, suffers from certain shortcomings, and that of Baker and Smith in *Eucalyptus* will serve to illustrate some of the errors which must be avoided in researches in this field.

Firstly, chemical data have sometimes been obtained from material from plants of imperfectly-understood or ill-defined systematic position. The genetic complexity of many populations is now familiar: in such cases species limits become blurred, and the chemical data drawn from such populations may become difficult to interpret. Thus, Baker and Smith reported on the oils of many eucalypts now known to be of hybrid origin; for example, *E. vitrea* R.T.Bak. (=*E. pauciflora* Sieber × *E. dives* Schau. or × *E. radiata* Sieber ex DC.), *E. irbyi* R.T.Bak. et H.G.Sm. (=*E. dalrympleana* Maiden × *E. gunnii* Hook f.), *E. unialata* R.T.Bak. et H.G.Sm. (=*E. globulus* Labill. × *E. viminalis* Labill.) and many others. They further overlooked the complexity in some *Eucalyptus* groups such as Series Psathyroxyla of Blakely (*loc. cit.*), the "scribbly gums", and reference to their herbarium specimens shows that under the name *E. haemastoma* Sm. they included the variety *sclerophylla* Blakely and *E. racemosa* Cav. (syn. *E. micrantha* DC.). Penfold and Morrison (1927*b*, 1933*a*) demonstrated great chemical differences not only between *E. haemastoma* and *E. racemosa* but also within *E. racemosa*. Other examples of groups providing genetic difficulty are the *E. mannifera* Mudie group (Johnson, 1962), treated by Baker and Smith in part under *E. maculosa* R.T.Bak., *E. lactea* R.T.Bak., and *E. gullicki* R.T.Bak., and the *E. andrewsii* Maiden-*E. campanulata* R.T.Bak. complex (treated as two distinct species by Baker and Smith).

Secondly, some earlier theories have been based on deficient chemical data: in very many cases Baker and Smith had identified compounds comprising less than 50 per cent. of the oil (e.g. *E. dawsoni* R.T.Bak., *E. nova-anglica* Deane et Maiden, *E. fibrosa* F. Muell. (*in loc. cit.* "*E. siderophloia* Benth.") and *E. eximia* Schau. In the case of only a very few species did these authors have a knowledge of oil compositions accounting for the greater portion of the oil.

Thirdly, if chemical variation within a "good" species occurs, it will present problems in the accommodation of chemical data to a scheme relating them to the systematic position of a plant. This phenomenon will be referred to later, but at this juncture it may be recalled that Baker and Smith encountered variations in oil composition within a species, and that it caused them great difficulties in their schemes of classification and phylogeny. Their treatment of the phenomenon was inconsistent: in *E. viminalis* they simply admitted the difference, and designated the variant "variety A"; in *E. camaldulensis* Dehnh. (*E. rostrata in loc. cit.*) they formally erected the varietal taxon of *borealis* to differentiate those trees yielding an oil rich in cineole, but morphologically inseparable from those of populations earlier encountered, but which yielded a markedly different type of oil. In *E. radiata* Sieber ex DC. (*in loc. cit. E. australiana* R.T.Bak. et H.G.Sm., *E. phellandra* R.T.Bak. et H.G.Sm., and *E. amygdalina* var. *nitida* Benth.) separate taxa of specific rank were erected solely on chemical grounds. Finally, in *E. dives* Schau. the observation by these authors of a profound chemical variation (*E. dives* var "C" of Penfold and Morrison, 1927*a*) was so at variance with their scheme that they rejected these trees as belonging to *E. dives* and referred to them as "*E. australiana* var. *latifolia*".

Finally, attempts to classify plants by chemical groups (as did Baker and Smith in *Eucalyptus*) may be misleading unless an adequate knowledge of oil compositions is available. These workers were compelled to establish a category for species "yielding an oil not readily placed in the other groups". Their theory of correlation of leaf venation with chemical composition of the oils suffered from the existence of this category: *E. citriodora* Hook., for example, with its venation (and all other characters) typical of Series Corymbosae-peltatae of Blakely, failed to yield an oil rich in α-pinene, but was found to contain citronellal as major component. Research continues to demonstrate the existence of species whose leaf oils are of unexpected chemical composition. Sutherland, Webb and Wells (1960), for example, showed the leaf oil of *E. deglupta* Blume from New Guinea to consist largely (*c.* 50 per cent.) of nerolidol, together with ocimene, α-pinene, α-phellandrene, *p*-cymene, carvatonacetone and *iso*valeraldehyde; and Hellyer, Keyzer and McKern (1964) have found that the leaf oil of *E. crenulata* Blakely et de Beuzeville consists largely of methyl 3,4,5-trimethoxybenzoate (*c.* 47 per cent.) and γ-terpinene, accompanied by lesser amounts of *p*-cymene, α-pinene, terpinolene, *iso*valeraldehyde, and terpen-1-en-4-ol.

The lesson to be learned from this review of earlier work is not only that data must be interpreted more critically, but that the phytochemist must also collect his data more critically against a background of awareness of the biological factors involved. Willis, McKern and Hellyer (1963), for example, suggest the following experimental procedure: (1) Collect chemical data (at least initially) only within well-defined species. (2) Working always on the same organ, compare oils of individual plants within the one population, or from the same site. (3) Compare data from population to population, or from site to site. (4) Test the inheritance of both chemical and morphological characters. This procedure may then with advantage be applied to plants or populations of plants where taxonomic limits are less clear (e.g. between *Pinus halepensis* and *P. brutia*, cf. Mirov, *loc. cit.*, pp. 111, 130–131).

II

The threads of chemical affinity already referred to, and which appear to link taxa already accepted from morphological considerations as related, undoubtedly exist and have received much attention. Not so much prominence, however, appears to have been given to the equally frequent lack of obvious chemical connection between closely-related taxa. The genus *Backhousia* (fam. Myrtaceae) provides an example. It is a small genus from which only nine species have been described. The genus itself is well separated from other cognate genera within the family, and further, species limits within the genus are sharply defined, so that no taxonomic difficulties are present. Of the nine species known, seven have been examined for their leaf oils; reference to Table I demonstrates the lack amongst these species of an obvious chemical linkage of the sort being discussed.

The use of the "unusual" or infrequently-encountered essential oil constituent as a means of tracing affinities amongst plants has already been referred to. Some guidance as to the reliability of this procedure is provided by the work of Bowyer and Jefferies (1959, 1962) on the incidence of torquatone in *Eucalyptus*. This substance was first discovered by these workers in the leaf oils of *E. torquata* J.G. Luehm. and of *E. caesia* Benth., and was shown by them to have the structure IV shown above. Of a further 40 species examined, another two showed the presence of torquatone: *E. flocktoniae* Maiden and *E. spathulata* Hook. var. *grandiflora* Benth. Significant points emerging from this study are: (i) As the authors themselves remark, "the four species found to contain torquatone are considered to have

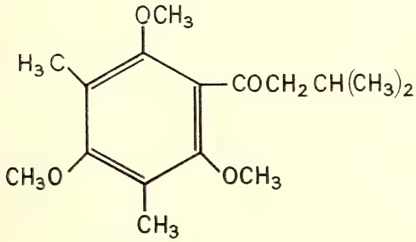
TABLE I

Leaf Oils of Backhousia *Species*

Species	Chief Constituents of Oil	References
B. angustifolia F. Muell.	(*a*)*Dehydroangustione; angustifolionol. (*b*) Dehydroangustione. (*c*) Angustione; angustifolionol.	Cannon and Corbett (1962)
B. anisata Vickery	Anethole	McKern (1949)
B. bancroftii F. M. Bail. et F. Muell.	Chiefly sesquiterpenes and sesquiterpene alcohols; α-pinene; esters.	Lahey and Jones (1938)
B. citriodora F. Muell.	(*a*) Citral, 90–95 per cent. (*b*) Citronellal, 62·5–79·7 per cent.; isopulegol; citronellol; esters.	Penfold *et al.* (1951)
B. hughesii C. T. White	α- and β-pinene; sesquiterpenes and sesquiterpene alcohols.	Jones and Lahey (1937)
B. myrtifolia Hook. f. et Harvey.	(*a*) Elemicin. (*b*) Isoelemicin. (*c*) Eugenol methyl ether. (*d*) Isoeugenol methyl ether and isoelemicin.	Penfold (1922); Penfold, McKern and Spies (1953); Hellyer, McKern and Willis (1955).
B. sciadophora F. Muell.	α-pinene, 80–85 per cent.; sesquiterpenes and sesquiterpene alcohols.	Penfold (1924).

* The alternative entries (*a*), (*b*), (*c*) or (*d*) in the centre column refer to differences in oil composition occasioned by the existence of chemical races or forms within the species.

very little botanical affinity" ; *E. caesia* (series Obliquae), *E. spathulata* (series Cornutae) and *E. torquata* (series Dumosae) are widely enough separated within section Macrantherae, but *E. flocktoniae* (series Subulatae of section Platyantherae) is, at least on Blakely's classification, of little affinity with the other three. (ii) The species found by Bowyer and Jefferies not to contain torquatone comprise six from series Dumosae, closely related to *E. torquata*, and another six from series Cornutae and having close botanical affinity with *E. spathulata*.



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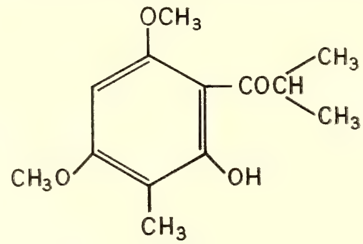
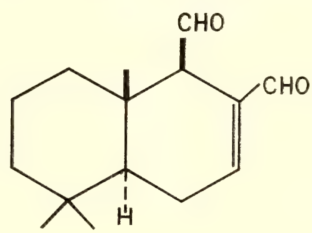


V

E. griffithsii Maiden is classified as related to *E. caesia*, also in series Obliquae. (iii) Further, gas chromatographic examination of the oil of typical *E. flocktoniae* showed no indication of the presence of torquatone ; this substance was detected only in a form having ribbed fruits from the Lake King district of Western Australia. With *E. spathulata* var. *grandiflora*, only one sample (from the large-fruited form from Lake King) yielded an oil containing torquatone.

Another aromatic substance, baeckeol (V), provides a further example of the inconclusive results of following the incidence of the "unusual" compound : discovered first in the leaf oils of *Baeckea imbricata* (Gaertn.) Druce (*B. crenulata* R.Br. *in loc. cit.*) and of *Darwinia procera* B. Briggs (*D. grandiflora in loc. cit.*) by Penfold (1922*b*, 1923), the same author (1925) demonstrated its presence in *B. gunniana* Schau. var. *latifolia* F. Muell. (but not observed in *B. gunniana* by Smith (1922)), whilst Spoelstra (1931) later found it in the extra-Australian *B. frutescens* L. ; and quite recently Bowyer and Jefferies (1962) have shown it to be a component of the Western Australian *Calytrix angulata* Lindl. Baeckeol is thus seen, from an evolutionary point of view, to be diffused through at least three* genera of the Myrtaceae extending from southeast Asia to both the eastern and western extremes of the Australian mainland. Investigations on the oils of other *Baeckea, Darwinia* and *Calytrix* species have not disclosed the presence of baeckeol (Baker and Smith, 1899 ; Penfold, 1927 ; Jones and White, 1930 ; Penfold and Morrison, 1933*b* ; Penfold, Ramage and Simonsen, 1934 ; Bick and Jones, 1940 ; Jones, Lahey and Sutherland, 1949).

In fact, the unusual compound is likely to be found in plants widely separated in botanical classification. Consider the aromatic ester methyl salicylate : it is not commonly met in large percentages in essential oils, but nevertheless forms the major part of the oil of the angiosperm *Gaultheria procumbens* L. (Ericaceae) and of the botanically remote *Asplenium lamprophyllum* Carse (Aspleniaceae), a pteridophyte (Briggs and Taylor, 1947). Furthermore, these authors record that they failed to detect this



VI

ester in *A. bulbiferum* Forst. f. (almost indistinguishable from *A. lamprophyllum*), in *A. lucidum* Forst. f., in *A. flaccidum* Forst. f., or in *A. falcatum* Lam.

Again, it would appear that sesquiterpene dialdehydes are uncommon plant constituents ; nevertheless, the first two reports on a substance of this class, polygodial (VI), are from two widely separated families. Barnes and Loder (1962) first discovered polygodial in the leaves of *Polygonum hydropiper* L. (Polygonoceae)

* And four, if (as seems likely) the yellow crystalline substance of m.p. 104° found by Jones and White (1931) in the leaf oil of *Leptospermum luehmannii* F. M. Bail. (*in loc. cit. Agonis luehmanni* (F. M. Bail.) White et Francis) is baeckeol.

and in the same year Loder (1962) found it in the quite unrelated *Drimys lanceolata* (Poir.) Baill. (Winteraceae).

To sum up, whilst it must be admitted that some soft of a frequency pattern of volatile oil compounds has emerged (for example, the extraordinary frequency of occurrence of α-pinene), nevertheless, the selection of an " unusual " or infrequently encountered compound as a taxonomic tracer is scientifically unsound ; its unfamiliarity may be due simply to insufficient investigation. The eudesmols were once thought to be confined to *Eucalyptus* ; they are now known to occur in widely separated genera.

Further, not only does it appear that the same compound is likely to be encountered in the oils of unrelated species, but it seems that oils of very similar, if not identical, composition may be produced by plants from different species, genera, or separated by even higher taxonomic categories. McKern (1956) has suggested that, rather than attempt to link oil compositions with taxonomy, it would perhaps be better to think in terms of the biochemical system operative within the plant, on the assumption that this genetically-determined enzyme system results in the elaboration of a certain set of compounds which collectively constitute the oil. Hence it may be possible to recognize groups of oil compositions to one of which the plant may be linked, rather than to attempt to relate the composition of a single oil, or a selected component, to a taxonomic system. Unfortunately, our knowledge of the ultimate compositions of oils is still very far from complete, but there are strong indications that the compositions of oils from a number of different plants may be similar. In *Eucalyptus*, for example, it is not possible in our present state of knowledge, to distinguish qualitatively amongst the oils of the " piperitone form " of *E. andreana* Naud., of *E. dives* Schau., of *E. radiata* Sieber ex DC., of *E. piperita* Sm. or of *E. racemosa* Cav. In such work, care must be taken that artefacts (arising perhaps from the method of isolating the oil) are not confounding factors.

III

The simple correlation of volatile oil composition with the systematic position of a plant is likely to be complicated by the frequently-reported examples of chemical variation within a species. This phenomenon appears to have been observed for most chemical classes of secondary plant products, e.g., in alkaloidal plants (Steinegger, 1957), in glycosidic plants (Van Os, 1957), and in cyanogenetic plants (Dillemann, 1957), and has been the subject of much useful review and comment (cf. Mothes, 1957 ; Hegnauer, 1957 ; Dillemann, 1959). These authors are concerned with the phenomenon of pronounced chemical differences existing between plants or between populations of plants within a species which is otherwise well defined by the usual morphological criteria, and where no morphological character may be seen to be linked with a chemical character. The term " chemical races " has come into use for reference to these variants, which Hegnauer (1957) defines as follows : " In allgemeinen wird man von chemischen Rassen sprechen, wenn man innerhalb einer Species deutliche chemische Differenzierungen beobachten kann, die nicht von erkennbaren (oder erkannten !) morphologischen Differenzierungen begleitet sind." Hegnauer further emphasizes that these taxa are to be regarded as of sub-specific rank.

In the field of volatile oil chemistry, this phenomenon was first clearly perceived by Penfold and Morrison (1927*a*) as a result of their observations on *E. dives*, and, in the succeeding years their school in Sydney, together with many other workers in other parts of the world, have brought to light a large number of examples. Some of these have been discussed by Stahl (1957) and by Hegnauer (1957), but to emphasize the problem which this phenomenon sets the phytochemical systematist and phylogenist, the examples selected for inclusion in Table II have been chosen because in each instance the variants were observed growing side by side on the same site. The reader is further referred to Table I where, of the seven *Backhousia* species listed, three (*B. angustifolia*, *B. citriodora* and *B. myrtifolia*) are seen to exist in different chemical forms. These examples are of like interest, inasmuch as in the case of each species the chemical variants are also to be found occurring naturally side by side under similar environmental conditions.

At the time of writing, the evidence for chemical races within species showing not only quantitative chemical differences, but also those of a pronouncedly qualitative nature, is both strong and striking. However, the chemical data on which it rests must be regarded as incomplete, inasmuch as no chemist has yet accounted for every constituent of an oil. Even with the use of gas chromatography, perhaps not more than 99 per cent. of an oil has been accounted for, and in the remaining

TABLE II

Chemical Variation Within Some Essential Oil-bearing Species

Species	*Melaleuca bracteata* F. Muell.		
Chemical variety	1	2	3
Major components of oil . .	Eugenol methyl ether.	Isoeugenol methyl ether.	Elemicin.
Reference	Penfold, Morrison, McKern and Willis (1950).		
Species	*Melaleuca quinquenervia* (Cav.) S. T. Blake		
Chemical variety	1	2	3
Major components of oil . .	Nerolidol (*ca.* 90 per cent.)	Nerolidol and linalool (15–50 per cent.).	α-Pinene, 1,8-cineole, (—)-limonene, α-terpineol, viridiflorol.
Reference	Hellyer and McKern (1955) under *M. viridiflora* Gaertn.		
Species	*Leptospermum liversidgei* R. T. Bak.		
Chemical variety	1	2	
Major components of oil . .	Citral, linalool, α-pinene.	Citronellal, isopulegol, α-pinene.	
Reference	Penfold (1922, 1931) ; McKern (1956)		

1 per cent. may be found compounds whose presence may modify our views. Of the great majority of essential oils whose compositions are reported in the literature, few have had more than a dozen or so components recorded. However, the most recent examinations of essential oils by gas chromatography show that an oil may contain well over 100 components, of which most are present in only minute quantities, perhaps as little as 100 parts per million or less. The application of such refined analytical techniques will undoubtedly shed much light on the nature and extent of chemical variation in essential oils, but much remains to be done. In order to disprove the theory of chemical races (differing qualitatively from each other) in essential oil-bearing plants, a great number of compounds will have to be positively identified in perhaps less than 1 per cent. of the variant oil in order to establish its qualitative identity with the norm.

An instance of progressive refinement of knowledge of chemical variation within a species is provided by the recent work of Gottlieb, Magalhaes and co-workers (1959, 1960, 1962) on physiological forms in *Ocotea pretiosa* (Nees) Mez (Lauraceae) in Brazil. The wood oil of this species had long been considered to consist principally of safrole, but in 1960 these workers announced the occurrence of a form whose oil contained the unusual constituent, 1-nitro-2-phenylethane, together with much eugenol methyl ether. However, on closer examination of the oils from individual trees they showed (1962) that the oil of the nitrophenylethane form may contain varying amounts of safrole, whilst the safrole form, apparently devoid of nitrophenylethane, may contain eugenol methyl ether. The pattern, however, was further complicated by the detection of camphor in small amounts (1–4 per cent.) in some trees of the safrole form, but not in others.

A re-examination of many of these variant oils is therefore clearly called for ; but even should this result in the theory of qualitative variation being abandoned,* the fact of discontinuous variation in the percentage of a single constituent from, say, 1 per cent. in the oil of one plant to 90 per cent. in the oil of an adjoining plant of the same species, both plants occurring naturally on the same site and free to interbreed, is of great genetic interest and economic significance. This is not completely

* In fact, Flück (1963) asserts that " Reports of qualitative variation characterized by the fact that one or more substances are *completely* absent in one or more subdivisions of the taxon, and which is, therefore of interest to chemical taxonomy, should always be regarded with suspicion."

a hypothetical example; it is based on the observations of Hellyer and McKern (1955) on the leaf oils of *Melaleuca quinquenervia* (Cav.) S.T. Blake (*in loc. cit., M. viridiflora* Gaertn.) (*vide* Table II). These authors, working on single trees, observed, *inter alia*, that trees of this species yielding oils consisting almost entirely of nerolidol (*ca.* 90 per cent.) were growing side by side on the same site with other trees of the same species whose oils consisted of a complex mixture (1,8-cineole, viridiflorol, α-pinene, limonene, α-terpineol, etc.), in which nerolidol was not detected. *M. quinquenervia* is an exceedingly well-defined species in the area studied, in fact very distinct from all other members of the genus in New South Wales and shows no hybrid tendencies with other *Melaleuca* species.

IV

Setting aside for the moment the extensive data on chemical races, and assuming a chemical constancy for the species, what appear to be the present prospects of utilizing essential oil compositions in plant systematics? Replies to this question have recently been given by two research groups in this field.

The first opinion is that of Aplin, Cambie and Rutledge, who last year (1963) took up again the lead provided by the presence of phyllocladene and *iso*phyllocladene in the Gymnosperm genera already referred to. Using the more delicate technique of gas chromatography not available to earlier workers, these authors described the results of the examination of the leaf oils of 28 species of the Podocarpaceae and of nine other related Gymnosperms. They examined carefully the incidence of the diterpene hydrocarbons phyllocladene, *iso*phyllocladene, kaurene, *iso*kaurene, rimuene and cupressene. After tabulating and considering their data, they came to the following conclusion: "It would appear from the present survey that the diterpene hydrocarbons are of doubtful taxonomic value. From the observation that these compounds were absent in five species distributed over three of the sub-sections of the genus *Podocarpus* and whose natural habitats are quite distinct, the presence of these compounds is not even diagnostic of the family. Moreover, no clear patterns of characteristic constituents emerge for the different genera or sub-sections of the family."

The second opinion on the question of the utility of chemistry in taxonomy of essential oil-bearing plants is expressed by Mirov, whose monograph (1961) on the *Pinus* turpentines was earlier referred to. It will be recalled that his work covers the entire genus as it is at present known, and it is considered that the following quotations from his monograph are a fair summary of the present position; and although uttered specifically in reference to the *Pinus* turpentines, may equally well apply to other fields of phytochemistry:

"Some closely-related pines may possess turpentines of different compositions; on the other hand, it is known that two species taxonomically remote have turpentines of almost identical composition . . .

"The chemical composition of turpentine is not always correlated with the taxonomic position of a pine. One reason for absence of relationship is incomplete knowledge of chemical composition of pine turpentines. Another reason is that there is still a great deal of disagreement among botanists as to the classification of pines . . .

"Evolutionary development may also explain certain absences of relationship. Most likely, morphological and chemical characters have followed different paths of evolution.

"In correlating the composition of turpentine with the taxonomic position of a pine, one should remember that the genus *Pinus* of today is different from the genus of the Tertiary period. The oldest living species is probably not older than Miocene. The chemical relationship of pines that existed during the Jurassic was most likely different from what it is now. During the evolution of the genus, many ancient species became extinct, and many new species appeared. At present we have merely patches of an old biochemical pattern. Some of these patches are difficult to fit into the present structure of the genus; others fit very well and are useful in understanding the relationship of living pines . . .

"At present it would be futile to develop a natural classification of pines based on their chemical characters. We can merely claim now that chemistry and taxonomy of pine species often coincide, and that when morphological characters are ambiguous, a knowledge of chemistry of the turpentines may be useful."

From what has been said, the value of the chemistry of essential oils in relation to taxonomy appears limited. However, it is submitted that much more information is needed before assessing the worth of the systematic *rôle* of these substances. Indeed, the successes attending the application of other phytochemical products in this field should stimulate further research: a good

example is the weight of chemical evidence brought forward by Price (1963) and Ritchie (1964) to determine the taxonomic position of *Flindersia*.

Using modern methods, therefore, and having regard for some of the principles enunciated, the systematic examination of complete taxa of generic rank and higher should be undertaken. Some co-ordination between workers in different classes of plant product is required : this paper has been confined to volatile oils ; that is, to compounds having boiling-points from, say, 150° C to 350° C. This is an arbitrary division of secondary plant products, and it is certain that the plant knows nothing of vapour pressures. The study of essential oils alone, therefore, does not present a complete biochemical picture. For example, Erdtman (1956), in studying heartwood extractives of *Pinus*, was able to distinguish not only the genus, but was also able to distinguish chemically the two sub-generic taxa, Haploxylon and Diploxylon. On the other hand, Mirov, working on the turpentines distilled from the oleo-resins, was unable to do this. The overall picture of the secondary chemical constituents of plants is needed, bearing in mind that some chemical compounds of different structure may be biochemically related, and that certain substances may arise through more than one biosynthetic pathway.

Acknowledgements

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Heterocyclic Chemistry, and Some Biological Overtones*

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Introduction

Mr. President, Ladies, and Gentlemen, I am indeed happy, and feel honoured, that the Royal Society of New South Wales chose me as this year's Liversidge research lecturer. I received the whole of my undergraduate training at the University of Sydney, first in Pharmacy and later in Science. Because I enrolled first in 1926, I was too late to come under Liversidge's *direct* influence, for in 1908 he had vacated the Chair of Chemistry after 35 years' tenure and he died in England in 1927. Yet his influence is felt by all scientists in Australia.

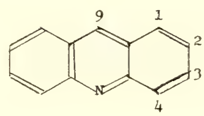
Archibald Liversidge, F.R.S., saw the whole of science as a single subject. At the age of 21 he worked in the Physiological Laboratory at Cambridge, whereas in Australia his chosen research field was mineralogical chemistry. As a constant background to this research, Liversidge was carrying out the organisational work for which Australian science will always be grateful. Edgeworth David wrote in 1931 that he thought Liversidge the greatest organizer of science that Australia has ever seen, and that he worked most unselfishly and with great singleness of purpose to advance the cause of science in Australia. " In 1879, after homeric battles with the powerful forces of Arts, he succeeded in winning for Science a Faculty of its own " (David, 1931). In 1885 he launched ANZAAS with the help of Australian and New Zealand colleagues, and this was, perhaps, his greatest work of all.

I had the good fortune to be chosen to give the Liversidge Centenary Lecture in 1946 at the ANZAAS meeting in Adelaide, and it is pleasing again to be doing honour to this great man.

Because my deepest interest, ever since schooldays, was to find out how drugs exerted their curative action, I studied biology alongside chemistry all through my undergraduate course. To-night I propose to describe some of the highlights of the research in which I became involved after completing my Ph.D. work in London and returning to Australia in 1937.

Monoaminoacridines

In my thesis work, under the supervision of W. H. Linnell, I had synthesized a number of new polyaminoacridines but the reason why only some of them were antibacterial quite eluded us. It was later, while I was working in the Department of Organic Chemistry in the University of Sydney, that I resolved to simplify the problem by examining the *mono*aminoacridines. It can be seen from the formula of acridine (I) that five isomers are possible.



Acridine

(I)

After preparing all five, I had the good fortune to interest my contemporary, S. D. Rubbo (now Professor of Bacteriology in the University of Melbourne), to test them on bacteria. The results were very clean cut : two isomers (the 3- and the 9- amino-derivatives) were highly active, and the other three isomers were almost inactive.

While I was wondering why this was so, an inner voice seemed to say, " It's the basic strength ". Naturally I was tempted to disregard this inner prompting, because the suggestion did not follow logically from the evidence, and could only be tested by mastering a new technique. All of my undergraduate and postgraduate training had stressed that advances are made by logical analysis of the experimental evidence in the light of established principles. To teach a student how to proceed in this way, is one of the principal aims of formal tertiary education.

Fortunately there is another mental process available to the research worker. Whether this is referred to as " inspiration " or " intuition ",

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it seems to depend on a portion of the brain that functions something like a computer, and tirelessly but unconsciously combines all sorts of odd strands of knowledge until finally it offers up to consciousness something that seems worth considering at that level. In giving credit to this process, which I am convinced is the research man's best friend, I do not want to undervalue formal education. It is only by the use of the formal universal language of science that ideas received in this way can be expressed in words, a process necessary both for their experimental testing and ultimate publication. But I must record also that in my mature scientific life I have met many bright young men, who, although they have absorbed an excellent formal training and can tackle any problem that one gives them, nevertheless can only proceed by small, logically-derived steps. Of course, we all have to do this when "inspiration" doesn't come, but possession of this ability alone does not seem to be enough qualification for undertaking full-time research, particularly in the difficult borderline subjects where so few principles are established. In other words, it seems fair to expect a proportion of discoveries to be surprising discontinuities, and not just inevitable extrapolations of known lines of work.

To return to my monoaminoacridines, I was shown how to determine their ionization constants by an honours student in Physical Chemistry. This was R. J. Goldacre who, by a steady broadening of interests, has become a Reader in Biology in the University of London.

The results of my collaboration with Rubbo and Goldacre are exemplified in Table 1. It is seen that two of the monoaminoacridines are much stronger bases than the others, that these two are far more highly ionized under the conditions of the test, and that these two isomers are by far the most highly antibacterial. This early success, led us to extend our approach to other acridines, about 106 of them in all, and to a wide range of pathogenic bacteria (aerobes, anaerobes, and Gram-positive and -negative species). As a result of this work, it became evident that the substituents did not influence antibacterial action except in so far as they influenced ionization. So long as the substance was substantially ionized as a cation at the pH of the test it was highly antibacterial, and actively fell as ionization fell. Even the poorly antibacterial monoaminoacridines of Table 1 could, by lowering the pH to below the pK_a values, be made to inhibit such organisms as *E. coli*, which grow well at low pH values (Albert *et al.*, 1941, 1945).

TABLE 1

Examples of dependence of bacteriostasis on ionization in the acridine series

Test organism: *Streptococcus pyogenes*, incubated for 48 hours at 37° and pH 7·3.

Medium: Meat broth, plus 10% serum.

Acridine	pK_a in water at 20°	Per cent ionized (pH 7·3 and 37°)	Minimal bacteriostatic concentration
			1 in—
Unsubstituted	5·60	1	5,000
1-Amino ..	6·04	2	10,000
2-Amino ..	5·88	2	10,000
3-Amino ..	8·04	73	80,000
4-Amino ..	4·40	<1	5,000
9-Amino ..	9·99	100	160,000

A search of the literature revealed that this was the first correlation of ionization with a biological effect although there was one (unproven) suggestion of such a correlation (Stearn and Stearn, 1924), and one established correlation between antifungal action and *non*-ionization (Vermast, 1921).

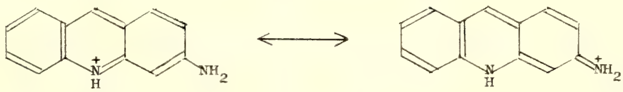
Ionization Constants

Reverting to chemistry, I wanted to establish why these isomeric aminoacridines differed so much in basic strength. Inspection of the formulæ suggested that possibilities for resonance, of the type (II)⟷(III) existed in the cations, but not in the neutral species, of three of the isomers, namely the 1-, 3-, and 9- derivatives. Now, we had found that the 3- and 9- isomers had high basic strength (e.g. 20,000 times that of acridine for the 9-derivative), but the 1-isomer lacked it. We provisionally concluded that base-strengthening resonances of the type (II)⟷(III) were significant if paraquinonoid forms were involved, e.g. (III) and (IV), but not if neighbouring orthoquinonoid rings were created, as in (V) (Albert and Goldacre, 1943; *cf.* Gore and Phillips, 1949).

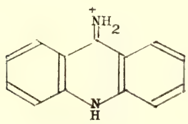
We then decided to transport to other series this concept of base-strengthening through the participation of a *p*-quinonoid form in the cation. At that time (1943), very few ionization constants of heterocyclic compounds were known (and hence few published ultraviolet spectra depicted pure ionic species). Sure enough, we found our base-strengthening principle upheld in the quinoline, pyridine, and many other nitrogenous heteroaromatic series (Albert *et al.*, 1948). The later demonstration by Angyal and Angyal (1952) that the neutral species were

primary amines, and not imines, rounded off this picture very well.

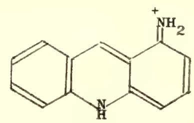
By now, I had developed an interest in ionization constants that has always remained with me. This interest has proved its worth over and over again, whether for identification, for settling a point of constitution, for choosing the best pH to give a maximal yield in preparative chemistry, or for obtaining those *single species* ultraviolet spectra that alone are



(II) (III)

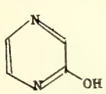


(IV)



(V)

significant. It has led to writing a book on methods for determining ionizing constants (Albert and Serjeant, 1962) ; and also a review and compilation of heterocyclic pK_a values (Albert, 1963). One of the most interesting research projects of this kind, was the determination of the ionization constants of 87 hydroxy-derivatives of various heteroaromatic nuclei and the estimation of the proportion of enol to amide forms present at equilibrium, e.g. (VI) and (VII)



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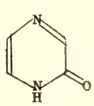


(VII)

respectively. This proved often to be as little as 1 part in 100,000 (Albert and Phillips, 1956). Parallel studies of mercapto-heterocycles gave similarly interesting results (Albert and Barlin, 1959).

Significance of Flat Area for Antibacterial Properties

I should like now to return to the antibacterial work. In 1942, our highly potent 9-amino-acridine* was taken up by the Australian Army for use as a safe and effective dressing for badly infected war wounds. It was then adopted by the British Pharmacopoeia (in the latest edition of which it has displaced acriflavin) and the non-proprietary name Aminacrine was given it (" Monacrin " is one of the brand names). This was the first of the non-staining acridine antibacterials.

Although this clinically useful drug was culled in wartime from scientific studies that had been given a strong *applied* leaning because of the war, I do not think it desirable that University work during times of peace should be aimed at the discovery of new drugs. Rather should it be directed to discovering the principles responsible for drug action. Industry is much better equipped for the discovery and marketing of new remedies, but seldom has it the time or inclination to devote to the fundamental research for principles. If universities did not do this, who would do it ?

In 1946, S. D. Rubbo and I decided to investigate the antibacterial properties of cations other than those of acridines. We found that by removing a benzene ring from 9-amino-acridine to give 4-aminoquinoline (VIII) all antibacterial action was lost. The same thing happened if a benzene ring in 9-aminoacridine was reduced to give the 1-, 2-, 3-, 4-tetrahydro-derivative. Yet all these substances were completely ionized under the test conditions. It occurred to me that a minimal *flat* area (about 38 sq. Å) was required before a molecule could have the antibacterial properties of an amino-acridine. (These properties can be defined as follows : active at high dilution, against a wide range of Gram-positive and -negative bacteria, even in the presence of protein.) To test this idea we added, to the molecule of 4-amino-quinoline, a styryl-group to give 4-amino-2-styrylquinoline (IX), which proved to be a powerful acridine-type antibacterial. Encouraged by this and similar successes, we attached the highly ionizing guanidine group to the anthracene nucleus (which has the requisite flat area) and thus achieved a typical " amino-acridine " action in a non-heterocyclic series (Albert *et al.*, 1949).

* This was known, in those days, as 5-aminoacridine, before the advent of the I.U.P.A.C. numbering.

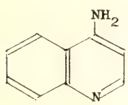
TABLE 2

Decrease of bactericidal action as concentration of oxine is increased
Staph. aureus, in meat broth. Plated out after 3 hours at 20°

Oxine 1/M	200,000	100,000	50,000	25,000	12,800	6,400	3,200	1,600	200
Growth ..	+++	—	—	—	+	+	+	+++	+++

Code : +++, growth was prolific ; +, up to 50 colonies ; —, no growth.

Recent studies in the U.S.A. have shown that aminoacridines accumulate between the flat layers of purine and pyrimidine bases in deoxyribose nucleic acid (Lerman, 1963), and this may be their site of action.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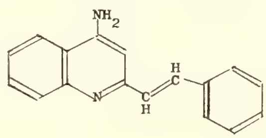
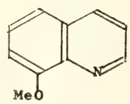

(IX)

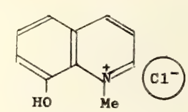
In the course of this acridine work some highly novel acridine syntheses and reactions were discovered, but these always seemed of secondary interest to the interdisciplinary studies in which the products were used.

Chelates

In a new collaboration with S. D. Rubbo, the mode of action of 8-hydroxyquinoline, a potent bactericide and fungicide, was investigated. This substance had long been used in analysis to segregate the ions of di- and tri-valent metals, and hence it seemed reasonable to suggest that its biological action was due to chelation (Albert, 1944). As has happened so often in the history of ideas, this suggestion was rejected by many as impossible, whereas to-day it is so well received that it now seems almost too obvious to mention! The biochemical grounds for rejection were that the human body contains many vital enzymes that have divalent metals as coenzymes, and hence a chelating agent would damage human and microbial cells equally. Many years later, it was possible to elaborate a quantitative basis for selectivity through, e.g. variations in stability constants, steric hindrance, and membrane permeability properties (which are related to partition coefficients). But in 1944 the first practicable method for determining stability constants was still being worked out, by Bjerrum, in Denmark.

Briefly, what we did in 1944 was to prepare the six isomers of oxine (8-hydroxyquinoline) and show that they neither chelated nor were they antibacterial. Next we examined the two methyl-blocked derivatives of oxine, respectively (X) and (XI), and showed that these had neither chelating nor antibacterial properties. Thus it seemed certain that the biological action of oxine depended on chelation. It would have been facile to suppose that oxine acted by removing an essential divalent metal ion from the bacteria. But careful observation soon convinced us that exactly the opposite was occurring, namely we found that oxine was quite inactive unless it was supplied with a heavy metal from the medium.


(X)


(XI)

The data which started this line of thought are shown in Table 2. It can be seen that oxine kills the test organism in a broth medium at a dilution of M/100,000, but progressively loses this property when the concentration of oxine is increased, so that a M/1600 solution has lost all bactericidal properties under the conditions of the test.

The explanation of this paradoxical "concentration quenching" came from the experiments performed in Table 3. The test organism, *Staphylococcus aureus*, was incubated in distilled water with oxine for an hour, and all organisms found to be alive, whereas when the same experiment was performed in meat broth, all organisms were killed. Clearly the broth contained a co-factor without which the oxine was inactive, and this factor proved to be iron. When an iron salt, ferrous or ferric, was added to distilled water, oxine killed all the bacteria. Conversely when iron was removed from the broth (by prior shaking with a chloroform solution of oxine), oxine failed to kill. The paradoxical results of Table 2 could now be explained by postulating that the 1 : 1 oxine-iron complex was the lethal agent, and that increasing the concentration of oxine without increasing that of the iron had produced the non-toxic 2 : 1

TABLE 3

Effect of oxine and of iron on growth of bacteria Staph. aureus, 20°. Plated out after 1 hour.

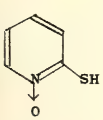
Oxine 1/M	Fe^{2+} or Fe^{3+} 1/M	Growth	
		Distilled water	Meat broth
Nil	Nil	+++	+++
100,000	Nil	+++	—
Nil	100,000	+++	+++
100,000	100,000	—	—

+++, growth was prolific ; —, no growth.

complex. We then showed that by maintaining a 1 : 1 oxine-iron ratio, oxine remained active even in the highest concentrations (Albert *et al.*, 1947, 1953). Cobalt was found to be a unique antagonist of this iron-oxine combination.

Later, working in London with different colleagues, I extended these studies to show that the activity of oxine derivatives was proportional to their lipophilic properties (as measured by oil/water partition coefficients) up to a plateau value. This suggested that penetration into the cytoplasmic membrane, or even into the interior of the cell, was a prerequisite for action (Albert *et al.*, 1954). By this time we had become quite skilled in determining stability constants, and brought these into the studies, to make sure that substances of similar metal-binding power were being compared.

Apart from straight derivatives of oxine, we found two other classes of antibacterial which were acting in the same way as oxine, in so far as they gave these same three tests : (i) less active (in broth) as the concentration is raised, (ii) inactive if iron is removed, (iii) inactive if both iron and cobalt are present (Albert *et al.*, 1956). These substances were 2-mercapto-pyridine-N-oxide (XII) and dimethyldithio-carbamic acid (XIII) and their derivatives.

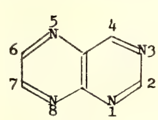


(XII)

$Me_2N.CSSH$

Dimethyldithiocarbamic acid.

(XIII)



Pteridine

(XIV)

Other workers extended our findings to other kinds of micro-organisms, namely : Williamson (1959) to the action of oxine on protozoa, Nordbring-Hertz (1955) to the action of oxine on yeasts, and both Anderson and Swaby (1951) and Block (1956) to the action of oxines on other fungi. Dimethyldithiocarbamate salts, which had long been dusted on crops as potent fungicides, were then shown also to act in the manner that we had worked out for oxine on bacteria (Sijpesteijn and Janssen, 1959). One small difference exists in the action of all these substances on bacteria and fungi : in the former iron is the co-toxicant, in the latter it is copper.

Our interest in chelation led us to discover and measure the metal-binding properties of the very successful antitubercular drug isoniazid (Albert, 1956), and of the tetracycline antibiotics (Albert and Rees, 1956).

Much of this work was done in London, where I went in 1947 as a Wellcome Research Fellow. In 1949, I was appointed to my present position by the Australian National University who asked me to stay in London until the John Curtin School of Medical Research was completed in Canberra. Meanwhile I was to hire laboratories, engage staff, buy apparatus and chemicals and commence research work. I was able to obtain suitable laboratories, mainly in the Wellcome Research Institution, but also others in University College, and Kings College. London provided a stimulating atmosphere in which to create a Research Department, but we were cramped for space, and expansion only became possible when we were able to move into the not quite finished John Curtin School in 1957.

Pteridines

Coincident with my joining the Australian National University, I took on a new research subject, the study of pteridine (XIV) and its derivatives. From their discovery by Gowland Hopkins in 1889, pteridines had been found only as constituents of insects, and their constitution was unknown before Purrmann's 1940 publications. The discovery in 1946 that the vitamin known as folic acid (XV) was a pteridine (Angier *et al.*, 1946), led to the discovery that a series of tetrahydrofolic acids were coenzymes in one of the most vital processes of the living cell, namely the synthesis of deoxyribose nucleic acid. These tetrahydrofolic acids, the pyrazine ring of which is shown in (XVI), have R=CH_3, or CH_2OH, or CHO, groups which are sometimes cross-linked to the nitrogen of the *p*-amino-benzoic acid portion. These coenzymes supply activated one-carbon fragments, from the R-group, for the biosynthesis of many cell-constituents, notably the 2-, and the 8-carbons of all purines, and the 5-methyl-group of thymine.

Fairly recently, another pteridine coenzyme has leapt into prominence. This is biopterin (XVIII) which enables molecular oxygen to

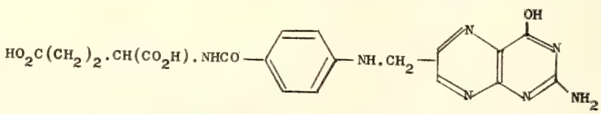
TABLE 4

Solubility of pteridines in water at 20°

Pteridine	1 in	Pteridine	1 in
(Unsubstituted)	7		
2-hydroxy	600	2,4,6-trihydroxy	7,500
4- ,,	200	2,4,7- ,,	12,000
6- ,,	3,500	4,6,7- ,,	27,000
7- ,,	900		
4,6-dihydroxy	5,500	2,4,6,7-tetrahydroxy	58,000
4,7- ,,	4,000		
6,7- ,,	3,000		

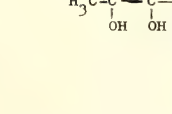
participate in such important cellular activities as the oxidation of phenylalanine to tyrosine, of dihydroxyphenylalanine to the skin pigment (melanin), of the glyceryl ethers of the brain to glyceryl esters, and of steroids to 17-hydroxy-steroids.

The opportunity to commence a study of pteridine chemistry pleased me very much, because very little of it was then known. Our aim was to correlate structure with physical and chemical properties, and to proceed from simple to complex derivatives. It was an abrupt change to work in a series where few substances have a melting point; but paper chromatography proved a valuable substitute, and gave so much insight into reactions and their products that I have come to consider it essential even when dealing with substances of definite melting point.

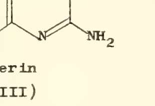


Folic acid

(XV)

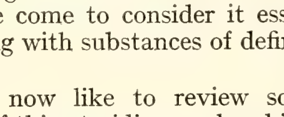


(XVI)



Purine

(XVII)



Biopterin

(XVIII)

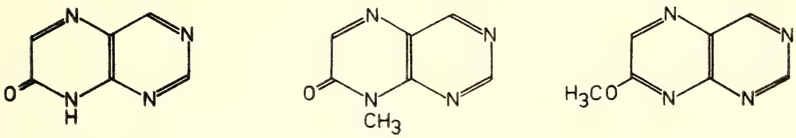
I would now like to review some of the highlights of this pteridine work, which still goes on, and with which the name of my colleague D. J. Brown is closely coupled. First of all, I should mention that we devised some new syntheses, including one where a purine, set aside at room temperature with a two-carbon reagent, is converted to a pteridine by ring-expansion (Albert, 1957). This is now known to be the process by which pteridines (and hence riboflavine) are formed in Nature. But I do not dwell on syntheses in any part of this lecture because, interesting as they are, the more scientifically exciting thing is what one does with the products.

The high insolubility of the butterfly wing pteridines (which arise by degradation of the above coenzymes) had led early workers to think that these were substances of high molecular weight. These pteridines have three or more water attracting groups (such as -OH and $-NH_2$) per molecule, and their insolubility in water was considered puzzling. By preparing a whole series of pteridines, with an increasing number of such groups, we were able to show that these so called water-attracting groups are the actual cause of the poor solubility in water (see Table 4).

Reference to Table 4 shows that pteridine itself is soluble in 7 parts of water (at 20°), and that each hydroxy-group added to this nucleus progressively decreases solubility (some smaller secondary effects are obviously imposed by positional isomerism). Our explanation was that these normally water-attracting groups were even more attracted to the nuclear nitrogen atoms of other molecules, thus producing a high crystal-lattice energy, and hence poor solubility. This was confirmed by showing that, when all bondable hydrogen atoms were blocked, either by O- or by N-methylation, the solubility in water actually increased although a hydro-

SOLUBILITY IN WATER

20°



1 in 900 | 50 | 50

Fig. 1

Solubility in water of 7-hydroxypteridine and its N- and O-methyl- derivatives

phobic group had been introduced, see Fig. 1 (Albert *et al.*, 1952).

The most pleasant feature of these results is that we found the same insolubilizing effect of -OH and $-NH_2$ groups in all N-heteroaromatic series with six-membered rings, from pyridine to the most complex nuclei. The effect greatly decreases as the number of doubly-bound nitrogen atoms in the nucleus decreases (Albert, 1959).

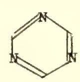
The naturally-occurring pteridines are noted for their resistance to hot, strong acid and alkali. However, inspection of the formula of the parent pteridine convinced me that it could have none of the chemical inertness of naphthalene or quinoline. The four doubly-bound nitrogen atoms, each equivalent to a nitro-group in inductive and mesomeric effects, seemed to be likely to attract the ten π-electrons and thereby cause such delocalization that aromatic stabilization would be severely reduced. The results, of treating a series of pteridines with acid and alkali, as in Table 5, gave substance to this idea. It can be seen that pteridine is indeed very labile, and that even one electron-releasing group is insufficient to counteract this weakness. However two hydroxy-groups have the desired effect, and the presence of three such groups gives complete stability to acid (Albert *et al.*, 1952).

Table 5

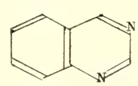
Decomposition of pteridines by acid and alkali

Pteridine	Decomposition 1 hour at 110°	
	$N\text{-}H_2SO_4$	10N-NaOH
(Unsubstituted)	74%	57%
2-Hydroxy-	55	89
4-Hydroxy-	60	94
6-Hydroxy-	2	100
7-Hydroxy-	52	76
2,4-Dihydroxy-	6	4
6,7-Dihydroxy-	7	12
4,6,7-Trihydroxy- . .	0	4
2,4,6,7-Tetrahydroxy- . .	0	6

Here again, understanding of a phenomenon in the pteridine series provided a general explanation of the instability of various heterocyclic nuclei of graduated π-deficiency. Thus, whereas pyridine is stable to hot, concentrated acid and alkali, pyrimidine is degraded by boiling N-sodium hydroxide, and *sym*-triazine (XIX) is completely hydrolysed by cold water



sym-Triazine
(XIX)



Quinazoline
(XX)

in one minute (formamide is the sole product). Yet, consistent with our pteridine studies, trihydroxytriazine (cyanuric acid) and triaminotriazine (melamine) are extraordinarily stable to hot acid and alkali.

Another interesting phenomenon in the pteridine series is photoreduction which occurs upon exposure to ultraviolet light for a few seconds. Thus 7-hydroxypteridine is converted to 5, 6-dihydro-7-hydroxypteridine, the hydrogen coming apparently from water (Albert, 1956).

Covalent Hydration

But the most interesting of all our discoveries has, so far, been the phenomenon of covalent hydration, interesting, too, because we extended the work to show that it occurs also in many other π-deficient heteroaromatic families. The abnormal titration curve of 6-hydroxypteridine, which forms a hysteresis loop (Fig. 2) was the first indication of this phenomenon. At first we suspected ring-opening and closing, but it was

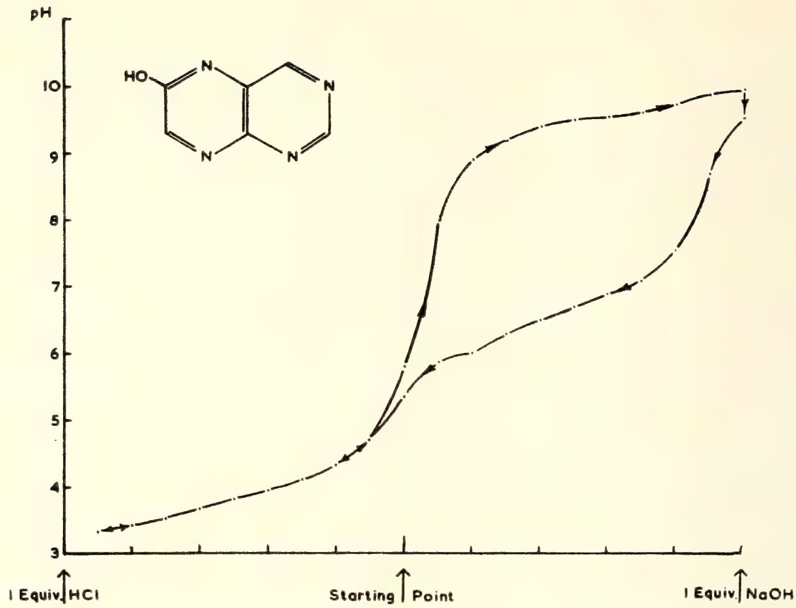


FIG. 2
Titration curve of 6-hydroxypteridine (hysteresis loop)

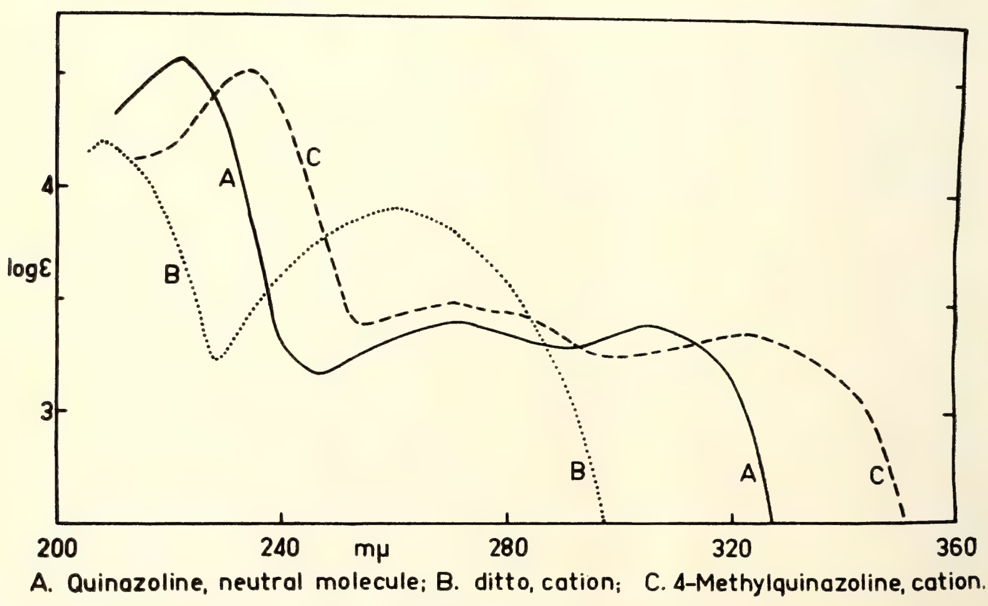


FIG. 3
Ultraviolet spectra of quinazoline and 4-methylquinazoline

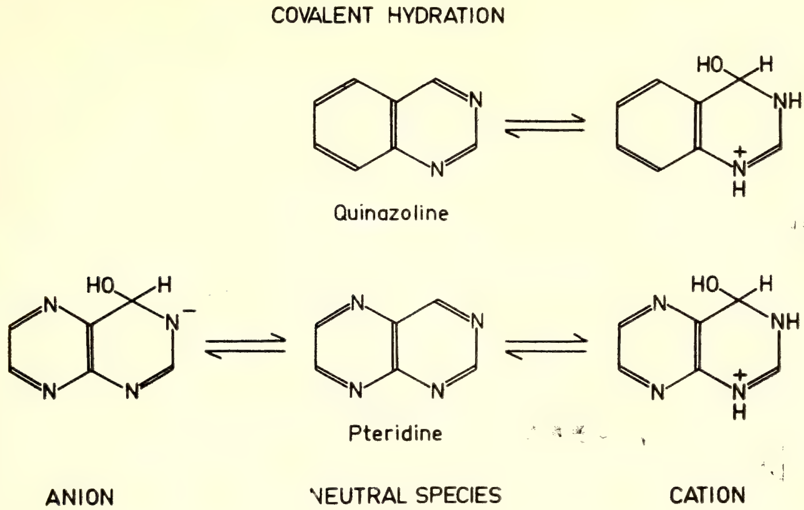


FIG. 4
The most stable of the various ionic species of quinazoline and pteridine

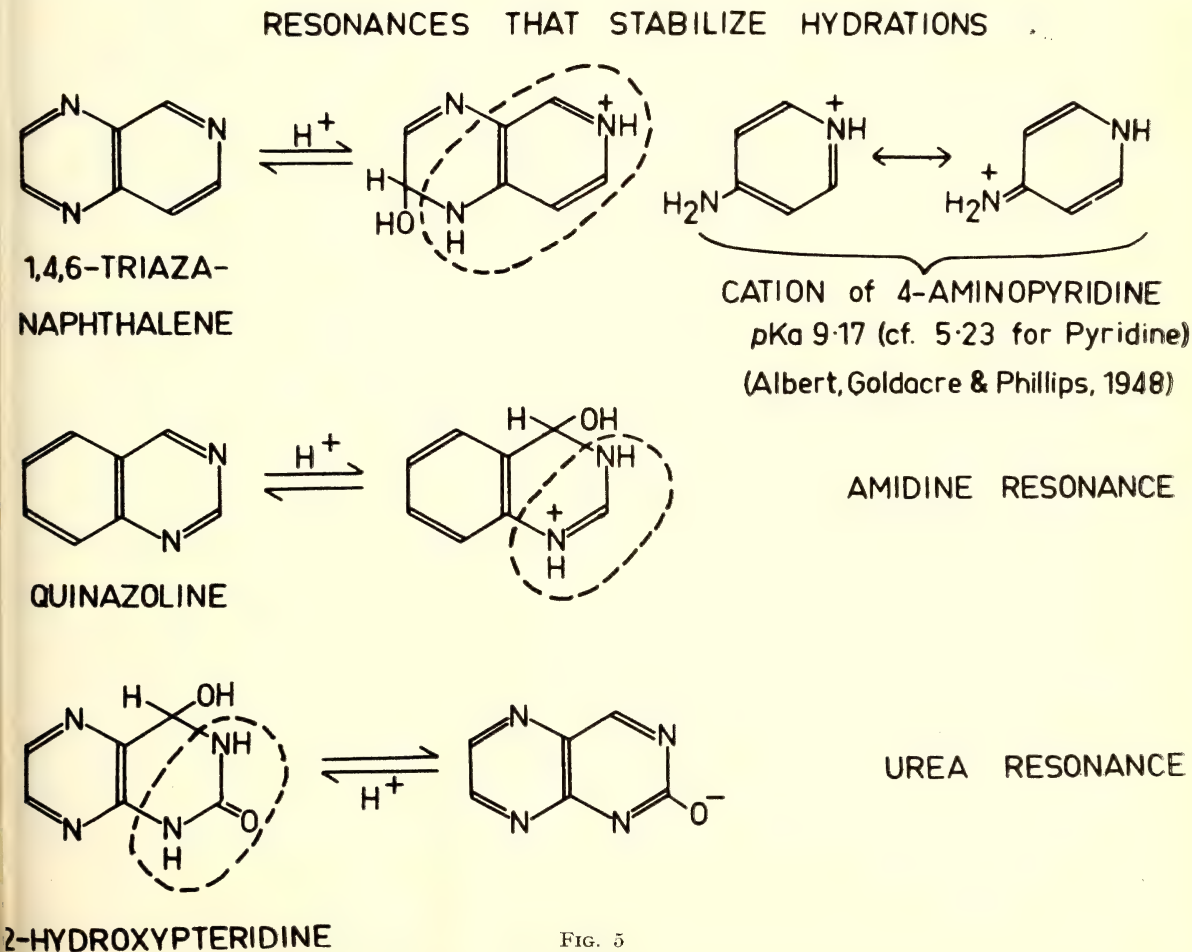


FIG. 5
Resonances that stabilize covalent hydrations

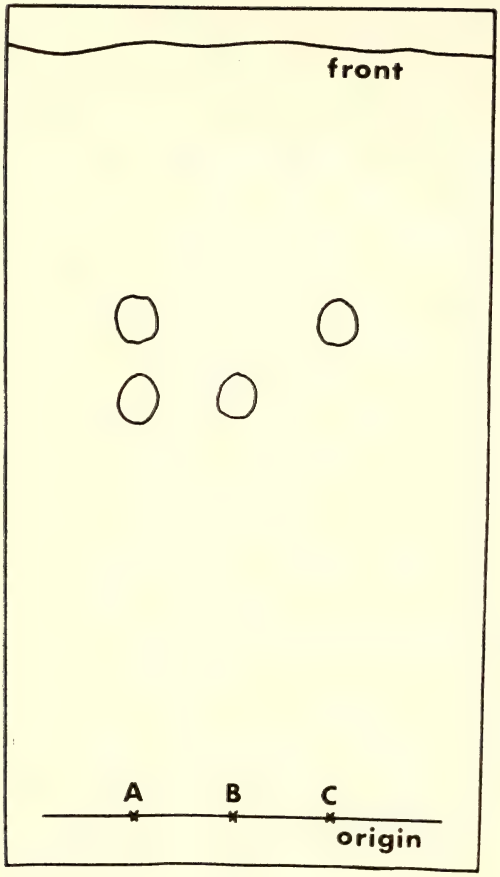


Fig. 6

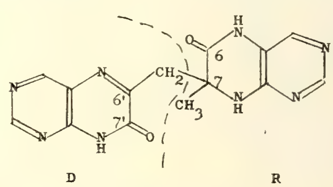
Behaviour of " Substance T " in paper chromatography (in water). A. Original solution. B and C. Eluates of the two spots from A

possible to exclude these in favour of the addition of water across a double-bond (Albert *et al.*, 1952 ; Albert, 1955). The location of the added water was determined by Brown and Mason (1956) who found that the hydroxyl-group went on to C-7, followed by the hydrogen on N-8. Their methods included comparison of the ultraviolet spectra and ionization constants with those of blocked derivatives, also infrared studies.

One of the simplest examples of this effect is furnished by quinazoline (XX). The ultraviolet spectrum of the neutral species of both quinazoline and 4-methylquinazoline are practically identical, but the spectrum of quinazoline is shifted to much shorter, and of 4-methylquinazoline to (the more normal) longer, wavelengths when each is converted to the cation (see Fig. 3). The correct explanation proved to be that each had an anhydrous neutral molecule, that quinazoline had a cation that was hydrated across the 3,4-position, and that the cation of 4-methylquinazoline was substantially anhydrous because of steric hindrance from the methyl-group (Albert *et al.*, 1961 ; Armarego, 1961).

Using the rapid reaction apparatus devised by Britton Chance, D. D. Perrin in my Department was able to obtain spectra of the two unstable species of quinazoline, viz. the hydrated neutral species and the anhydrous cation, and the true ionization constants, namely pK_a 7·77 for the two hydrated species and $\sim$1·9 for the two anhydrous species. Thus the published pK_a of 3·51 represents only an equilibrium value for all four species, and is of relatively little interest. Similar studies with pteridine gave the corresponding values for these equilibria. Pteridine proved more complicated than quinazoline in two respects : the neutral species was itself hydrated (at equilibrium to the extent of about 20%), and the hydrated form gives an *anion*, stabilized by resonance (see Fig. 4) (Perrin, 1962, 1963).

Time will not permit an account of all the nuclei in which we have found covalent hydration, nor of the valuable kinetic work done by Dr. Perrin assisted by Mr. (now Dr.) Inoue. It must suffice to give our ideas on the genesis of the phenomenon. Covalent hydration tends to occur in all π-deficient N-heteroaromatic molecules in which the electrons of the π-layer are heavily delocalized on the nitrogen atoms. This leads to the creation of an independently polarized C=N bond, the carbon of which becomes attacked by the negatively charged end of a water molecule. The hydration, induced in this way, is quantitatively significant only if the hydrated molecule is stabilized by a new



Substance T

(XXI)

resonance (Albert and Armarego, 1963 ; Albert and Barlin, 1963). Some of these stabilizing resonances are shown in Fig. 5. Two reviews dealing with covalent hydration were published recently (Albert and Armarego, 1964 ; Perrin, 1964).

Among the more interesting recent studies from my Department, an unusual note was

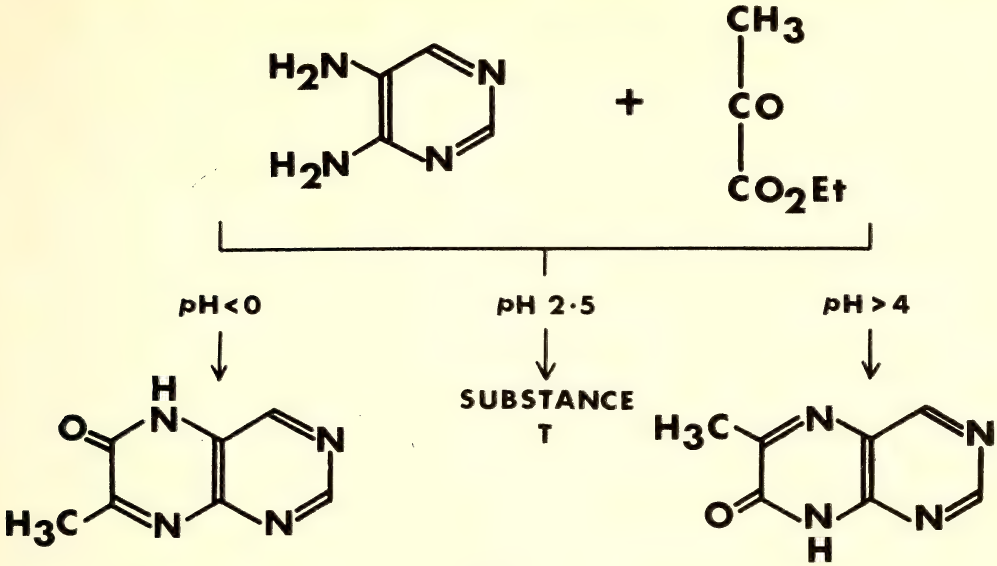


FIG. 7
Chart showing effect of pH on the production of pteridines from 4,5-diaminopyrimidine and ethyl pyruvate

struck by " Substance T ", so called because paper chromatography produced twin spots (see A in Fig. 6). Each of these, when eluted from the paper and re-applied, was found to correspond to one of the two original spots (see B, and C), and to have opposite optical rotations. This resolution had been effected by the cellulose.

The generation of Substance T, from 4,5-diaminopyrimidine and ethyl pyruvate within a restricted pH range as shown in Fig. 7, led to its formulation as the bipteridyl-methane (XXI). This was formed from 7-hydroxy-6-methylpteridine (D) acting as a Michael donor, and 6-hydroxy-7-methylpteridine (R) acting as a Michael receptor. The structure was proved by degradation. The underlying assumption, that Michael additions across a C=N bond can be *acid* catalysed, was verified by combining simple donors (such as acetylacetone) with simple receptors (such as quinazoline) (Albert and Serjeant, 1964).

In conclusion, I shall say only that, although we have ranged widely within the limits set by the title of this lecture, there are more kinds of heterocyclic chemistry with biological overtones to explore than have yet been laid hands on. Who can say what surprises the near future may bring ?

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Late Quaternary Coastal Morphology of the Port Stephens-Myall Lakes Area, N.S.W.

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Abstract—A vast array of Quaternary landforms and sediments occurs in the Port Stephens-Myall Lakes area of New South Wales. A study of this region's geomorphology, supported by some subsurface data, suggests that during late Quaternary the area experienced two main periods of deposition. These periods were separated by a phase of entrenchment which was associated with shoreline recession and lower sea level. Each depositional phase is recorded by transgressive deposits in the form of a bay-barrier. The older of these barriers (Inner Barrier) lies landward of the younger (Outer Barrier) so that, stratigraphically, embayment fill is in the form of an offlap sequence. The Inner Barrier is associated in time with a late Pleistocene high sea level stand, while the Outer Barrier is considered to have formed during the Recent period.

Introduction

The sand masses that connect the rocky headlands along the New South Wales coast offer great scope for research in coastal geomorphology and late Quaternary geology. Shepard (1960) has referred to features such as these as "bay barriers", an appropriate term in that they are separated from the country rock on the landward side by shallow-water lagoons or swamps.

In New South Wales there have been very few studies of sand deposits except from an economic point of view (Gardner, 1955). This is in contrast to recent work on the sand islands of southern Queensland (Coaldrake, 1962), in the Gippsland Lakes district of Victoria (Bird, 1961*a*), and around the shores of Tasmania (Davies, 1959, 1961; Jennings, 1959). Studies in other countries, particularly the United States, clearly show the value of geomorphic-geologic research of sand barriers. Shepard (op. cit.) has mentioned their importance in providing studies in active sedimentation, and that, as buried sand facies between two mud facies, they are potential traps for the concentration of petroleum. Also in terms of the latest period in geologic history, the Quaternary, these sand masses may represent different periods of deposition, so their study is of possible use in understanding the Quaternary, a relatively neglected period in Australian geology.

Regional Setting

The Port Stephens-Myall Lakes area has features that are characteristic of a drowned coast. Marine sediments, of mainly siliceous sand, fill bedrock embayments and attain depths of 100–200 feet below present sea level (cf. bore data in David, 1907, pp. 53–59; Griffen, 1959). Within the embayments sand barriers enclose lagoons whose configuration is to a large extent determined by bedrock topography. Many lagoons are now filled by freshwater swamp or estuarine sediments.

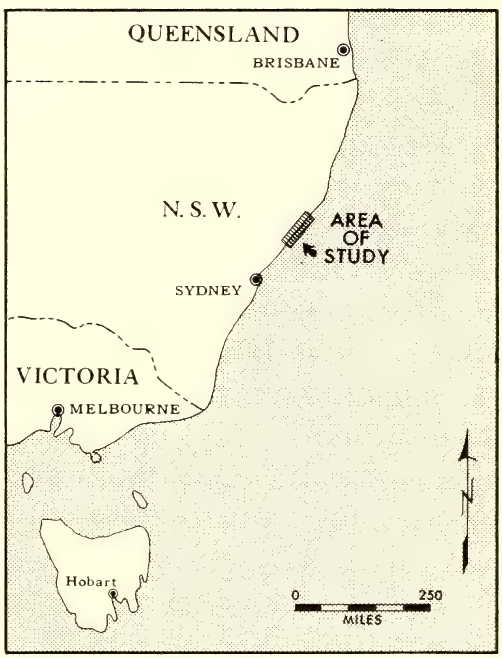

Fig. 1

Map showing location of Port Stephens-Myall Lakes area

The bedrock consists of folded Carboniferous strata (chiefly lithic arenites, conglomerate, mudstones and interbedded volcanics), the folds trending from due north to N 40° W (Engel, 1962). The relief inland is dominated by strike ridges up to 1,000 feet in elevation. Near the coast these ridges are dissected to below present sea level producing isolated rock outcrops, as at Broughton Island.

The region has a humid temperate climate which encourages the growth of plants upon the sand barriers. Rainfall averages 52 inches per annum at Port Stephens and Seal Rocks, while at Newcastle the average is 44 inches. Average monthly temperatures along the coast vary from 50–60° F in winter to 70–80° in summer. Onshore breezes dominate in summer, but in winter westerly winds generally prevail. At all times of the year southerly winds can be expected, usually accompanying storms.

Swell waves that are generated in southern parts of the Pacific Ocean are regarded as significant in the alignment of wave-built coastal deposits in southern Australia (Davies, 1960; Bird, 1961*a*). These waves promote beach fill in this area as do waves locally generated by north-easterly winds in summer. South-easterly swell predominates in winter, and it is common in this season for local storm winds to generate high energy wave conditions, which may cause considerable destruction of beach and foredune areas.

Except along exposed sections of the shoreline where active sand dunes are characteristic (Fig. 2, Plate II), sand deposits are covered by trees and shrubs varying in height from a few feet to 80 feet as in the eucalypt forest near Seal Rocks. In general, the soils under vegetation tend to be weakly to strongly podsolized, the intensity of podsolization varying with the age of the deposit and topographic position.

Coastal Landforms

Floodplains, Deltas, and Terraces

Within the bedrock embayments of this coastal stretch several types of landforms can be recognized which are the product of fluvial, paludal, lacustrine, estuarine, and marine processes during the late Quaternary period. Floodplain deposits consisting of levees, backswamps and filled channels of cut-off courses, form narrow strips along steep-sided valleys of the Karuah and Upper Myall Rivers and Boolambayte Creek, while the levees of the Karuah River extend beneath the waters of Port Stephens. These levees are partially covered by mangroves. At the southern end of the region the Hunter River forms a more complicated delta which is filling in an estuary produced by entrenchment during the last glacial period.

Older floodplains now in the form of river terraces line the sides of the bedrock valleys. They are most extensive in the Hunter River Valley where more than one terrace can be recognized. Radiocarbon dating of intact bivalves (*Anadara trapezia*) from within a terrace at Largs (>37,000 B.P.) at an elevation of 18–19 feet above H.W.M., indicates that this and higher terraces are of Pleistocene age. Largs is located 19 miles inland from the sea. Terraces also exist along the Upper Myall River upstream from the town of Bulahdelah.

Lagoons

More striking physiographic features within the embayments are the coastal lagoons (locally called lakes) enclosed by sand barriers. Lagoons vary greatly in size and shape depending on proximity to bedrock and relationship to barrier systems. For instance, the Myall Lakes are a series of interconnected water-bodies of irregular shape formed behind sand barriers with their shorelines abutting bedrock except on the seaward side (Fig. 2). Tilligerry Creek, on the other hand, and the swamps containing tracts of open water between barriers of the Fens and Eurunderee embayments are elongated parallel to the coastline and are of relatively uniform width.

Systematic data on the bathymetry, hydrology and salinity are lacking for these lagoons. However, certain general features are noted. Locally, depths in the Myall Lakes exceed 30 feet, but in general they tend to be less than 20 feet. Salinity varies from fresh in the Myall Lake to brackish in Broadwater Lake. Reversed drainage of freshwater occurs during floods as Upper Myall River discharge is directed from Broadwater Lake into the Myall Lake. Eventually flood waters escape to the sea along the tidally influenced Lower Myall River. This is a drainage channel into Port Stephens that follows an inter-barrier lagoon, now a swamp. Lunar tides are barely perceived in Broadwater Lake, but the water-level changes during floods when it has been observed to rise as much as 9 feet (1892 and 1927, H. Legge, personal communication).

Sediments in the lagoons are quite varied. Along exposed shorelines facing fetches of 1–4 miles in length, sandy beaches and beach ridges have formed. They are well developed along

the eastern shore of Broadwater Lake (Fig. 4, C–C′). Preliminary observations reveal that lake bottoms are composed of soft mud and fine organic debris.

At the exposed north-western end of the Myall Lake near the town of Bungwahl projecting promontories of country rock have been cliffed by waves. Irregularly shaped blocks rest on narrow rock platforms just above mean lake level. In the bays between promontories sand and pebble beaches are found. The pebbles are well rounded and appear to be reworked Carboniferous conglomerate observed outcropping in the country rock. The problem, however, is that both beaches and bluffs are relic features. Casuarinas grow on and in front of the rock platforms, while a reed and swamp tree fringe extends into the lake in front of the beaches. As no marine fauna or extensive aeolian deposits have been found along these shores, the writer has concluded that both cliffs and beaches are lakeshore features. Past periods of more frequent storms is one possible explanation, but within the past few decades a local resident from Bungwahl (Mr. M. Bramble) has observed that the Myall Lake is silting up in certain areas. The relic shorelines therefore suggest a decrease in the intensity of wave action accompanying the siltation of the lake.

Swamps and Bogs

Plants fringing the lagoons appear to be encroaching upon the remaining water bodies in a manner not unlike that described by Bird (1961*b*) in the Gippsland Lakes. In many cases little open water remains and former lagoons have been converted into peaty swamps or bogs. Elongated bogs occur in the inter-barrier lagoons of the Eurunderee embayment (Plate I) and in the funnel-shaped re-entrants between beach ridges of the Upper Myall valley (Plate II).

A number of generalizations can be gleaned from swamps and bogs in this area. First, siltation and swamp development are more advanced behind the innermost sand barriers. This point is well illustrated by the low-lying areas landward of Fens and Newcastle Bight embayments. Exceptions are the Myall Lakes where river discharge, depth of water, and length of fetch have inhibited complete enclosure.

Second, the nature of sedimentation and types of encroaching plants depend on the environment. Clays containing shells, commonly found in estuaries, and salt marsh and mangrove plants are significant in swamp development between Fullerton Cove and Tilligerry Creek and around the shores of Port Stephens. This contrasts with the organic-rich muds, silts and peats associated with freshwater plants of the Fens, Upper Myall and Eurunderee areas.

Port Stephens

Port Stephens as a geomorphic feature merits separate discussion. This extensive water body trends E-W and is open to the sea at the eastern end. On the northern side it is bordered by outcropping Carboniferous sediments. There is no evidence of aeolian deposits along these shores. The southern, eastern and western limits are, however, dominantly marine-aeolian deposits which link isolated Carboniferous outcrops to enclose Port Stephens (Fig. 2). Therefore, Port Stephens can be considered as a barrier lagoon with a perennial opening to the sea. Lunar tides are effective within this water body; the mean tide range of 4·2 feet at Nelsons Bay, just inside Port Stephens, is the same as at Broughton Island off the coast. This fact coupled with freshwater discharge of the Karuah River and Myall Lakes drainage produces an estuarine environment in Port Stephens.

The history of sedimentation in Port Stephens during the late Quaternary appears complicated. Discontinuous beds of shells up to 15 feet in thickness are scattered over the floor of the estuary. Little is known of their composition and depositional history. Large sand accumulations occur at the eastern end of Port Stephens with finer sediments dominating at the western extremity near the outlet of the Karuah River. In the discussion below of coastal barriers, a Pleistocene age will be suggested for the innermost barrier formed in the Newcastle Bight embayment. This interpretation implies that at least the western part of Port Stephens was an estuary during the last interglacial or interstadial high sea stand following deposition of the Pleistocene barrier. The estuary achieved its present form after Recent (post-glacial) deposition in the Newcastle Bight, Anna Bay, and Tomaree Hill Dune areas.

Beach Ridges and Sand Dunes

Hardrock headlands and isolated outcrops are linked by sand beach ridges. The alignment of these ridges within embayments appears to be determined by the wave fronts of refracted dominant swell which approaches from the south-east. Systems of multiple beach ridges, composed almost entirely of quartz sand, trend parallel to the shoreline indicating active accretion along this stretch of coast during the late Quaternary. It is possible to distinguish

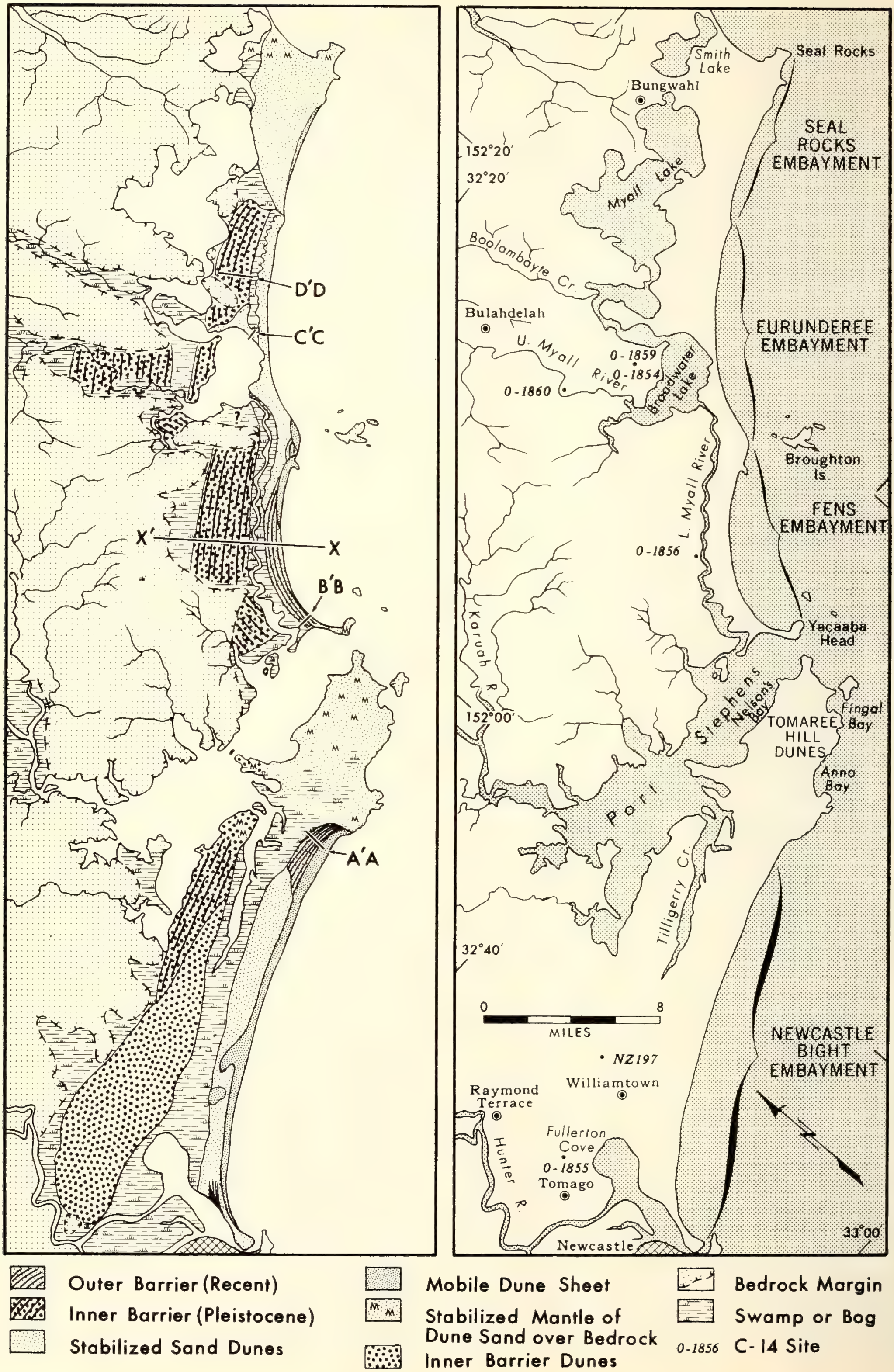

FIG. 2

Index map of the Port Stephens-Myall Lakes area showing the location of radiocarbon samples, and a map of surface morphology.

two beach ridge systems as separate depositional units, to be referred to as Inner Barrier and Outer Barrier (Fig. 2 and Fig. 3).

In many areas the surface of the barriers has been modified by wind action forming highly varied dune forms. An interesting aspect of geomorphic study in this area has been the recognition of this wide variety of dunes, including those referred to in the literature by such terms as longitudinal, parabolic and transverse (Thom and Simonett, in preparation).

Coastal Barriers

Description

Dual barrier systems are pronounced geomorphic features in the Newcastle Bight, Fens and Eurunderee embayments (Fig. 2). Similar systems exist along other parts of the New South Wales coast (Langford Smith and Thom, in press). South of the entrance to Port Stephens in the Tomaree Hill Dune area and in the Seal Rocks embayment, only one barrier surface is apparent. The intervening tract of lagoon or swamp is not present in these areas where windblown sand has moved inland from the sea and blanketed beach ridges and Carboniferous rock outcrops.

Field studies of morphology and soils, together with analyses of aerial photographs and bore data,[1] have strongly suggested that the barriers with their component beach ridges and dunes, are separated by a distinct time line. It is considered that these differences may be useful in distinguishing Pleistocene from Recent coastal sand deposits in other areas of south-eastern Australia.

1. *Inner Barrier System.* Sand beach ridges of the Inner Barrier system are characteristically of subdued relief, standing 1–6 feet above swales (Fig. 4, D–D′). The innermost, or first-formed, ridge crest usually stands 5–15 feet above the rest of the ridge series. Characteristically, this system encloses a swamp at the head of the embayment which is a relic of a former barrier lagoon. The linear pattern of these ridges is clearly seen on the air photographs (Plate I). Ridge spacing varies from 300–600 feet, and profiles in different localities show that a series of ridges may gently slope either landward or seaward.

Although the higher innermost ridge is forested, most sand ridges of this system are covered by low-growing scrub or heath. Generally the swales are water-logged and contain peat 1–2 feet in thickness. Belts of the paperbark (*Melaleuca leucadendron* sens. lat.) delineate the alignment of swales in many cases.

Inner Barrier ridges are composed of leached incoherent quartz sand, varying in depth from 2–12 feet, and overlying an organic-bound sandrock forming a hardpan. Not all hardpans in the coastal siliceous sands of eastern Australia have the same origin (Coaldrake, 1955), but the

[1] Made available to the writer by the courtesy of Hunter District Water Board (H.D.W.B.) and the N.S.W. Department of Mines.

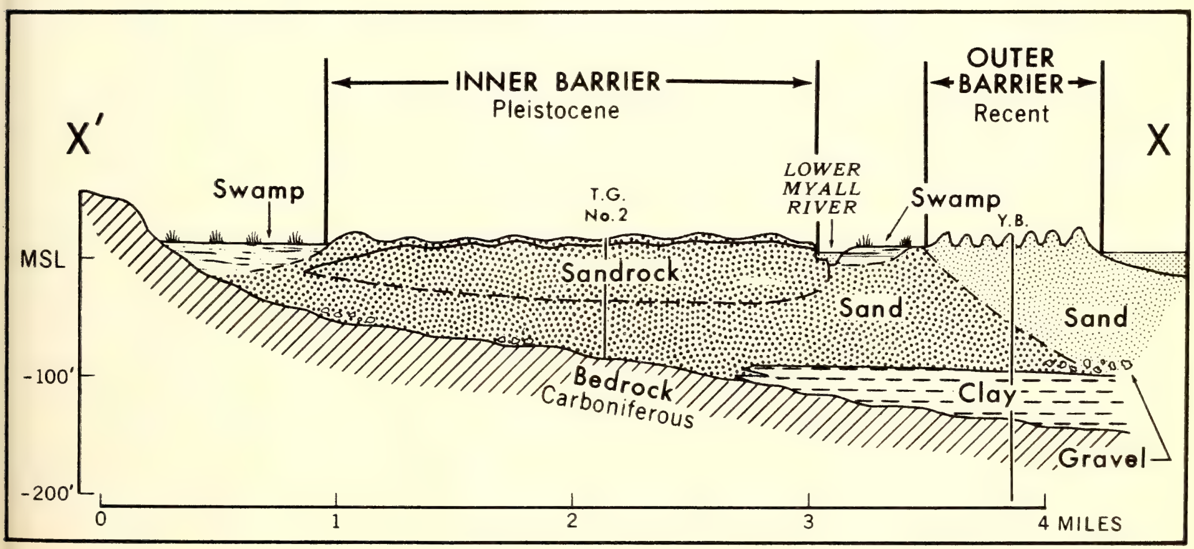

Fig. 3

Hypothetical cross section of the Fens embayment illustrating the writer's ideas concerning the relationship between Inner and Outer Barriers

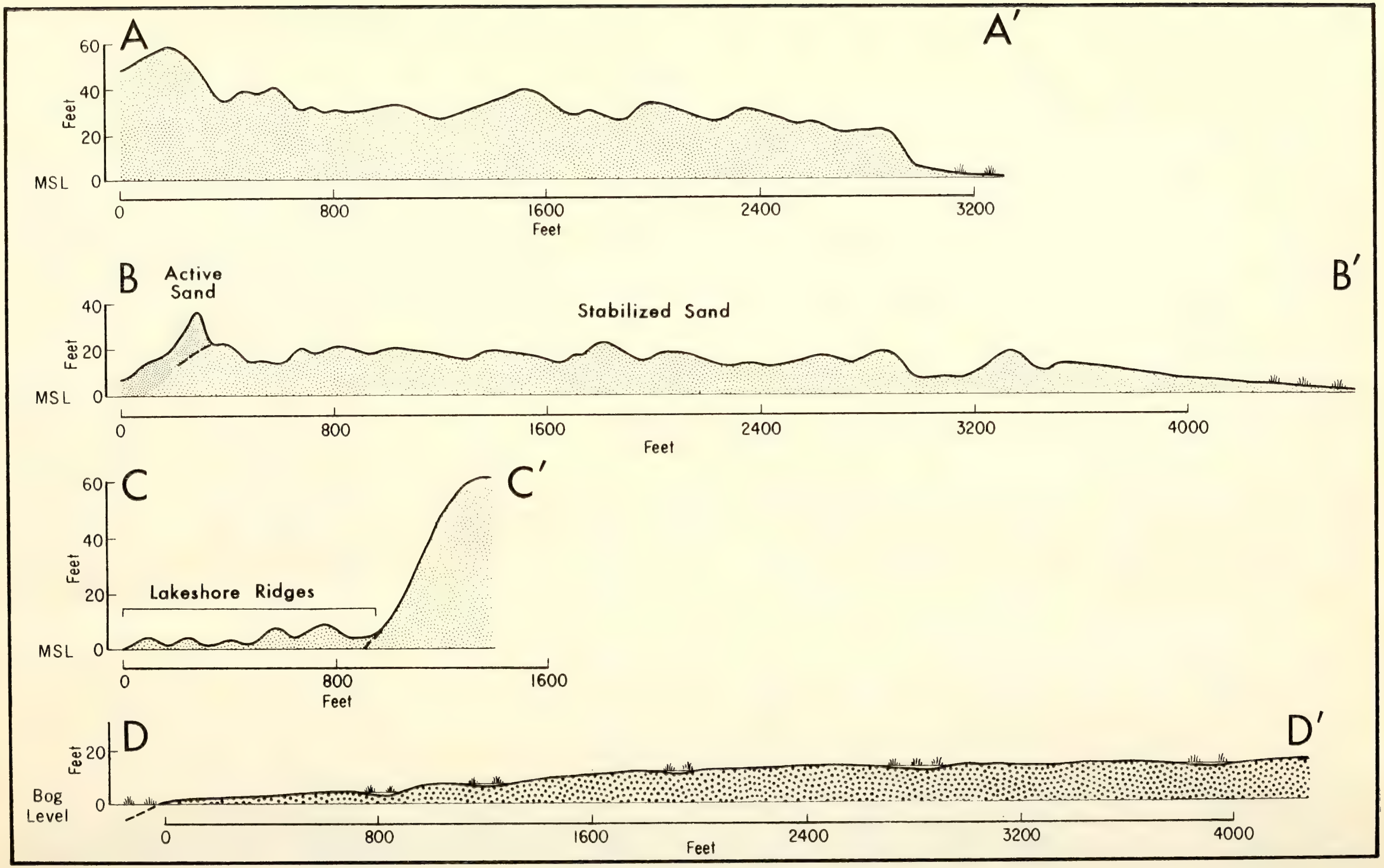

FIG. 4

Levelled profiles across beach ridges ; A–A′ Newcastle Bight Outer Barrier ; B–B′ Fens Outer Barrier ; C–C′ Broadwater lakeshore ridges abutting older parabolic dune ; D–D′ Eurunderee Inner Barrier

type beneath these beach ridges is considered to be the B horizon of a giant ground-water podsol. Although further work is necessary to substantiate this view, it is supported by the absence of macroscopic plant remains, the presence of humic colloids, and a relatively small amount of clay as cementing agents,[2] the presence of overlying leached sand, and by the occurrence of sandrock at a higher level beneath the ridge than beneath adjacent swales. Bore data show that sandrock occurs widely beneath beach ridges but is patchily distributed underlying areas of windblown sands, such as the longitudinal dunes of the Tomago-Williamtown area (Newcastle Bight embayment). The sandrock underlying beach ridges is known to vary in thickness from a few feet to 46 feet, the maximum thickness logged by the Hunter District Water Board. As the elevation of the beach ridges ranges from 5–30 feet above sea level, it is apparent that the sandrock extends below present sea level in many localities. This is observed on the cut banks of the Lower and Upper Myall Rivers where the ridges have been truncated by erosion, exposing the sandrock as low bluffs.

A further characteristic of Inner Barriers is entrenched channels, most of which are at present occupied by alluvial fill and peat. They appear to be cut channels formed at a lower base level, probably when sea level was lower than at present. Although this entrenchment is more clearly seen in other Inner Barriers of the New South Wales coast, the beach ridges that stretch inland for 6 miles in the Upper Myall River embayment have been truncated by the river. Swales of these ridges have also been entrenched (Plate III). In the Bombah Bog, peat and wood were recovered immediately overlying a sand horizon at approximately 15–16 feet below mean sea level. This material is overlain by a grey clay containing marine diatoms and peat of freshwater origin. Bore data clearly show that the peat and clay layers do not extend beneath adjacent beach ridges. The fill of clay and peat seems to increase in thickness towards the river. However, much more work is necessary before the nature of alluvial fill in these entrenched channels is fully understood.

Sand dunes on Inner Barriers are also subdued relief features. In the Eurunderee embayment a complex of parabolic dunes was recognized landward of the beach ridges (Plate I). The arms of these features are generally less than half a mile long, and tend to be in the form of imperfect crescents. Their troughs are now swamps. The dune sand is strongly podsolized.

Another area of dunes formed on an Inner Barrier is in the Newcastle Bight embayment (Fig. 2) where steep-sided ridges possessing a distinct E-W alignment cut across the trend of beach ridges. Podsol soils in this district, described by Maze (1942), are also well developed.

2. *Outer Barrier System.* The Outer Barrier system of sand beach ridges, located across the mouths of embayments, is separated from the Inner Barrier by a tract of shallow lagoon or swamp.

The characteristic ridge of this system has a sharper appearance than the Inner Barrier type. The difference in height between crest and swale varies from 4–12 feet, although locally a portion of a ridge may be 20 feet above adjacent swales. Outer Barrier ridges are also more closely spaced, the distance between ridge crests ranging from 60–300 feet (Fig. 4 A–A′, B–B′, Plate II). The seaward decrease in height characteristic of Tasmanian beach ridge systems (Davies, 1958, 1961) has not been observed in comparable areas between Newcastle and Seal Rocks.

Except in the vicinity of the foredune, being formed behind the present beach where soil development is lacking, the soils of Outer Barrier deposits are weakly to moderately podsolized. These soils consist of an ash-grey A horizon overlying a humic-stained, barely coherent B horizon. No hardpan has been recorded beneath the ridges of this system. The water table lies below the surface of the swales and, unlike Inner Barrier swales, hydrophytic plants are absent. The more landward ridges are covered by *Eucalyptus* forest with trees decreasing in height seaward. Near the foredune *Banksia-Leptospermum* scrub replaces the eucalypts.

The foredune of the Outer Barrier, behind the present beach, characteristically is a sand ridge attaining heights of 50 feet or more, particularly at the northern end of embayments. In most areas the seaward face has been eroded by storm waves to form a poorly vegetated sand bluff. This sand bluff is often fronted by a low ridge, or terrace, partially stabilized by pioneer sand binding plants.

In numerous localities the continuity of the foredune may be interrupted by blowouts. Further destruction of the foredune ridge by

[2] Iron oxides have been reported as a cementing agent in some hardpans found in swamps of the Newcastle Bight Inner Barrier (Maze, 1942).

lateral expansion of blowouts may leave a row of butte-like knobs or remanié dunes. The final removal of these knobs results in the formation of a mobile sand sheet which is driven inland as a broad front by onshore winds.

The stabilized equivalents of blowouts and inland-facing fronts of mobile sand sheets are well preserved as high relief dunes on Outer Barriers. In the Newcastle Bight and Eurunderee areas sand ridges, covered by eucalypts, may exceed 100 feet in elevation. Exceptionally high aeolian accumulations forming ridges and sand sheets mantle bedrock at Tomaree and Seal Rocks. In both localities dune sand has been observed up to 300–400 feet above sea level. In all four areas these dunes have transgressed older surfaces such as swamps, bedrock, or scrub and forested dunes. For convenience, dunes of this type, whether active or stabilized, are referred to as transgressive dunes. Morphological and depositional contacts are quite marked in areas where aeolian transgression has taken place (Plate II). A large exposure in the dunes behind the beach at Belmont, about 12 miles south of Newcastle, revealed a strongly podsolized soil covered in places by 30 feet of bedded dune sand. Tall trees now stabilize the surface.

Age of Coastal Barriers[3]

The problem of barrier age applies to the development of both Inner and Outer Barriers because of the sharp morphological and pedological discontinuity between the two systems. Bird (1961*a*, p. 466), in considering the development of the " outer barrier " in the vicinity of the Gippsland Lakes, Victoria, commented that :

> " The separation of the outer barrier [from earlier formed barriers] must indicate a relatively sudden emergence during Recent times, transposing the zone of barrier formation seaward . . . Under these conditions the outer barrier was initiated off-shore by wave action in water shallowed by emergence, in the way described by D. W. Johnson (1919)."

This hypothesis rests on two assumptions, neither of which is considered valid when applied to barriers between Newcastle and Seal Rocks. First there is the view that a postglacial eustatic fall of sea level has occurred (ibid., p. 466), and second, that all the barriers of East Gippsland are Recent in age (ibid., p. 460). The evidence from New South Wales for a higher stand of the sea during Recent times is not very convincing (Langford Smith and Thom, in press). Detailed regional studies in Europe by Jelgersma (1961), and in the United States by LeBlanc and Bernard (1954), Bloom (1959), Redfield and Rubin (1962), and McIntire and Morgan (1962) show a lack of evidence which would indicate submergence above present high tide level during Recent times. Russell (1963 ; and personal communication) strongly questions the eustatic interpretations of Fairbridge and Teichert along the Western Australian coast. In that area features cited as Recent in age appear more likely to be Pleistocene (ibid., p. 7).

The second assumption of Bird, that all the barriers of East Gippsland are Recent in age,[4] also seems inappropriate to the area under discussion. A pre-Recent (Pleistocene) high sea level age is suggested for the formation of the Inner Barrier in the Port Stephens-Myall Lakes area by :

(1) the hardpan that exists beneath the beach ridges and extends below present sea level,

(2) evidence of incision by streams into Inner Barriers, the cut channels at present occupied by alluvial fill,

(3) beach ridge systems on the Inner Barrier often attaining elevations of 20–30 feet above present mean sea level,

(4) the absence of a continuum between Inner and Outer Barrier beach ridge systems,

(5) the marked morphologic and pedologic contrast between the two barriers,

(6) the following list (Table I) of radiocarbon dates of material from Inner Barrier sites indicating that the deposition of barrier sand wedges of this type, with their component beach ridges, took place during a stand of the sea prior to the so-called Recent " stillstand ".

Only sample N.Z. 197 (Ferguson and Rafter, 1959) is in a stratigraphic position which predates the age of Inner Barrier deposition. The shell was reported to come from a layer of fine sediment immediately beneath the barrier sand wedge. The other six dates were recently made for the writer by the Geophysical Laboratory and Exploration Department of the Humble Oil Company, Houston, Texas.

[3] For further discussion of coastal barriers, especially those of the Gulf Coast of U.S.A., see Shepard (1960).

[4] Bird elaborates on this view in a more recent paper (Bird, 1962) ; however, based on further field work in 1963, Bird now considers that a Pleistocene age is possible for some of the Gippsland barriers (personal communication).

TABLE I

Sample No.	Location	Sample	Approx. Elev.	Age B.P.
N.Z. 197	Newcastle Bight I.B. (G.R. 9046 ?)	*Anadara* mollusc	—50 ft. M.S.L.	>33,000
0–1859	Bombah Bog (G.R. 303802)	Peat	—15–16 ft. M.S.L.	11,075±230
0–1854	Bombah Bog (G.R. 303802)	Peat and seeds	—6–7 ft. M.S.L.	3,675±120
0–1860	Upper Myall I.B. (G.R. 258842)	Humic colloids	+8 ft. M.S.L.	3,630±120
0–1856	Fens I.B. (G.R. 231670)	Humic colloids	+6 ft. M.S.L.	4,550±130
0–1855	Newcastle Bight I.B. (G.R. 753433)	Humic colloids	+15 ft. M.S.L.	3,050±115
0–1853	Belmont (G.R. 696173)	Charcoal	+30 ft. M.S.L.	13,000±280

These samples are of material which post-dates barrier formation. The charcoal at the Belmont site (0–1853) rests on a barrier surface which has been buried by layers of dune sand.

The channel-fill sediments from the Bombah Bog, discussed above, post-date the deposition of the beach ridges. The peat dated at 11,075±230 is probably of freshwater origin. As information from other areas shows that sea level 11,000 years ago was much lower than 15–16 feet below present M.S.L. (Shepard, 1961), it is reasonable to argue that the beach ridges in the Upper Myall Valley were deposited during a high sea stand of the late Pleistocene period. Channel cutting would therefore have occurred during a fall in sea level associated with the last glaciation, and the Recent eustatic rise is considered to have induced alluviation of the channels. The date of 3,675±120 at the base of the uppermost peat layer just above the clay containing marine diatoms may date only local environmental change or have more general significance.[5]

The three samples of humic colloids were collected from different embayments (Fig. 1). The colloids were extracted from hardpan (sandrock) material which lay beneath a leached zone of 2–3 feet thickness. Two of the samples (0–1860 and 0–1856) were obtained just below (18–24 inches) the top of the hardpan, 6–8 feet above M.S.L. In both cases the hardpan extends below sea level for an unknown depth. The third sample (0–1855) came from a hardpan exposure in the centre of the sand plain near Williamtown. Illuviation of the colloids as part of the formation of a groundwater podsol is the suggested mode of accumulation. Such a phenomenon must post-date the deposition of the barrier, and therefore the age of the colloids at the base of the hardpan is probably greater than the 3,000–4,000 year dates obtained near the top. Clearly, more sandrock material is needed for radiocarbon analysis at depths below the dated samples.

The Outer Barriers of the Port Stephens-Myall Lakes region are interpreted as late Recent in age. A significant geomorphic factor suggesting this is the lack of dissection quite typical of Inner Barriers along the New South Wales coast (Landford Smith and Thom, in press). Dissection appears to be associated with a major change in sea level and hence stream base level. Systems of beach ridges comprising Outer Barriers would therefore have been formed during the late Recent when sea level was at or near its present position.

It has been difficult to find dateable materials beneath Outer Barriers. However, at Belmont, 12 miles south of Newcastle, a date was obtained: Sample 0–1849 should be treated with caution because the local stratigraphy is complicated, and possibly the sample was contaminated. However, it did come from beneath a parabolic dune which on morphology and soils evidence belonged to the Outer Barrier. Stratigraphic

[5] Dr. A. R. H. Martin is at present undertaking a stratigraphic and palynological study of this bog.

TABLE II

Sample No.	Location	Sample	Approx. Elev.	Age B.P.
0–1849	Belmont (G.R. 703174)	Charcoal and peat	—46–48 ft. M.S.L.	8,075±175

data supplied to the writer by Dr. A. K. Temple show that the podsolized Inner Barrier surface lies landward of the site of sample 0–1849.

Origin of Coastal Barriers

It is therefore considered valid to assume two periods of barrier formation, and that the Inner Barriers are Pleistocene in age, and the Outer Barriers have formed since the sea level rose to its present position in Recent times after lowering during the last glacial period. This assumption is a prerequisite to the following analysis of barrier origin.

Unfortunately bore data are inadequate beneath the barriers to establish accurately the bedrock profile. Most H.D.W.B. bores do not extend this far. The meagre information available indicates that depths to bedrock vary greatly. David (1907) and Griffen (1959) report depths of 192, 115 and 201 feet beneath the Outer Barrier in the Newcastle Bight embayment. In these bores the thickness of undifferentiated sand, overlying clay and gravel, was recorded as 176, 95 and 110 feet respectively. The Duckhole bores beneath the Inner Barrier show 73 and 84 feet of sand with bedrock at 150 and 212 feet respectively (ibid). There are no accurate topographic controls on bores from this embayment, so differences in depth may mean variation in bedrock relief and/or variation in the elevation of bores above sea level.

Two bore holes in the Fens embayment, T.G. 2 and Y.B., although not exactly located on the section XX′ of Figure 2, have been used in the construction of the hypothetical diagram of embayment fill stratigraphy (Fig. 3). T.G. 2, a Hunter District Water Board bore, struck bedrock at 90 feet. The thickness of sandrock in this bore is 44 feet. The Y.B. bore, located nearer to Yacaaba Head on the Outer Barrier, encountered clay at 91 feet and bedrock at 163 feet (ibid.). Shallow holes of the H.D.W.B. and the writer, in both barriers, are the basis for surface contacts shown in Figure 3, but the bedrock profile is largely hypothetical.

It is not possible to test the hypothesis that the barriers are anchored on a surface lying within the expected range of wave erosion. This surface is considered to be 30 feet or less below mean low tide under normal conditions (Russell, 1958; McIntire and Morgan, 1962). Anchored barriers are noted in the United States along the Gulf Coast and the Atlantic Coast in the vicinity of Plum Island (ibid.). In such instances the innermost ridge is not envisaged as an emerged bar, but as an upward growing beach that rose over a Pleistocene subaerial surface during the rise of sea level, and when the sea reached its present position it anchored itself on this surface within the limits of effective wave activity. Zenkovitch (1962) has suggested a similar process for the origin of barriers which involves submergence of the land, and the landward shift of a shore ridge which forms a lagoon " in the place which have never been a part of the sea aquatorium " (p. 117).

The reason for the difficulty in testing the anchored barrier hypothesis in the Port Stephens-Myall Lakes area is that a possible anchor, the bedrock, occurs at unknown depths beneath the Inner Barrier, especially beneath the innermost ridge. Bedrock is certainly not the anchor for the Outer Barrier, but this does not preclude the possibility of a Pleistocene unconsolidated surface extending seaward from the Inner Barrier underneath the present Outer Barrier (dashed line in Fig. 3). As is the case of the Outer Banks, North Carolina (Dr. D. D. Smith, personal communication), the sand section appears uniform in bore logs. It may be extremely difficult to differentiate between Pleistocene and Recent sediments beneath the Outer Barrier because of apparent sediment uniformity, and the possibility of reworked Pleistocene material.

The inter-barrier lagoons of Newcastle Bight, Fens and Eurunderee embayments not only indicate a time break between periods of development of the two barriers, but also show that the sea has not come in contact with these Inner Barriers in Recent times. It is likely that a protective barrier beach existed seaward during the rising sea level stage. Near the end of this stage, approximately 3,000–4,000 years ago (Gould and McFarlan, 1959; McIntire and Morgan, 1962; Coleman and Smith, 1964) this beach reached the position of the innermost beach ridge of Outer Barriers. Subsequent to the development of this ridge the barriers have prograded forming multiple beach ridges.

Growth of Coastal Barriers

It is not intended in this paper to discuss all the possible origins of accretionary sand beach ridges. There are numerous studies on the problem, many of which were considered by Davies (1957). More recent research undertaken by members of the Coastal Studies Institute, Louisiana State University, U.S.A., will soon be published.

There are two main problems to be considered in the accretionary growth of coastal barriers

in this region. One is the development of ridge and swale topography; the other is the difference between Inner and Outer Barriers in spacing of ridge crests.

(1) Under conditions of available sediment in the nearshore zone, the beach accretes by deposition during calm weather waves. Aggressive sand-binding plants, such as *Spinifex hirsutus* and *Festuca littoralis*, may then grow seaward onto the beach until they reach a point which is frequently awash at high tides. Onshore winds move sand from the foreshore into this plant zone where it accumulates, forming a ridge parallel to the shoreline. Oscillation in the growth of the prograding beach controlling the seaward position reached by pioneer plants is suggested as the important factor in ridge and swale development. Ridges formed of a wave deposited base and an aeolian cap vary in height according to the thickness of wind-blown material. Therefore the height of the ridge is in direct relation to the length of time the strandline remained at a fixed position.

This hypothesis, the wave-wind hypothesis, is in contrast to the view that storm-wave deposits form beach ridges as observed along the shores of the Mexican Gulf coast in Tabasco and Campeche (Thom, 1964). Evidence for the wave-wind process is not fully conclusive, and more work involving studies of beach-ridge stratification and the distinction of wave from wind deposited sand remains to be undertaken in New South Wales. However, profiles across Outer Barrier ridges (Fig. 4, A–A′, B–B′) show considerable variation in relief. These should be compared with the profiles across ridges of the eastern shore of Broadwater Lake (Fig. 4, C–C′), which have been formed by wave deposition.[6] Wind deposition is insignificant here where *Casuarina* spp. and *Melaleuca* spp. fringe the lakeshore. These ridges compare favourably with those observed in Mexico both in form and apparent origin.

(2) Most marked in this coastal region is the difference in spacing between beach ridges of the Inner Barrier and those of the Outer Barrier. A similar difference has been observed elsewhere along the New South Wales coast, but it is not always present (Langford Smith and Thom, in press). Gill and Banks (1956) report this spacing difference between ridges of apparent Pleistocene age and those of Recent age located along the coast of north-western Tasmania. McIntire (personal communication) reports a similar phenomenon from the Cockburn Sound south of Perth. Investigations by the writer in Horry County, South Carolina, U.S.A., show that ridges on older and more landward Pleistocene barriers are more widely spaced than those on younger Pleistocene barriers. At present it is not possible to generalize to the effect that the older the barrier, the wider the spacing; or the more landward the barrier in an embayment situation, the wider the spacing, or whether the wider spacing is simply a function of time, and that degradation processes have caused the flattening of many ridges. Much more comparative work has to be undertaken in Australia and other parts of the world. Pleistocene barriers are well preserved along the Texas Gulf Coast (Price, 1933, 1947; LeBlanc and Hodgson, 1959) and south-east Brazil (Delaney, Coastal Studies Institute, in press).

Late Quaternary Geomorphic History

At present only tentative conclusions can be made regarding this region's geomorphic history. The basis for the following interpretation are the geomorphic and pedogenic contrasts between the two sand barriers, discussed elsewhere in this paper. A major time break is indicated by these contrasts, and this time break is considered to be the late Pleistocene fall in sea level accompanying the last glacial period.

As a first approximation, the late Quaternary geomorphic history of this coastal stretch may be summarized as follows:

1. *Late Pleistocene High Sea Level Stage.* During this period, corresponding to an interglacial or interstadial, wave and wind processes operating at, or slightly above, present sea level produced the Inner Barrier. It may be that the subdued parabolic dunes landward of beach ridges in the Eurunderee embayment were formed as the sea rose to this level following a previous glacial period. The Inner Barriers were constructed within embayments enclosing water bodies, many of which are now swamps. Stratigraphically it appears that beach and dune facies form a wedge tapering inland over discontinuous lenses of older Quaternary gravels and clays, which in turn rest upon a seaward-sloping bedrock surface.

2. *Late Pleistocene Lowering and Low Sea Level Stage.* The last glacial period (Wisconsin-

[6] The large ridge of Figure 4, C–C′, and associated dunes appear to ante-date the Outer Barrier which formed Broadwater Lake and the consequent diversion of Myall Lake drainage through the inter-barrier lagoon of the Fens embayment.

Würm) was characterized by a fall in sea level, possibly as much as 450 feet (Russell, 1957). Streams such as the Hunter, Karuah and Upper Myall, entrenched their valleys. The last mentioned cut through a beach ridge series. These valleys along with the shoreline extended seaward an unknown distance towards the edge of the continental shelf. Most sediment was deposited on the outer edge of the present shelf, the upper slope, and in deeper environments. Very little is known about the nature of sedimentation during this period.

3. *Early Recent Rising Sea Level Stage.* About 17,000 years ago sea level started to rise (Shepard, 1961) and transgress the subaerial Pleistocene surface. Unlike areas of the Gulf Coast of the U.S.A., it is not yet possible to identify this surface in the stratigraphic record. It may have been destroyed by reworking along the shoreline of the rising sea. The top of the clay reported from bore logs beneath Outer Barriers may be this surface. Associated with sea transgression has been the alluvial infilling of river channels and embayments by fine sediments, organics, and sand deposits. This phenomenon, referred to as alluvial drowning, has been reported from many other parts of the world (Russell, 1957).

The sandrock hardpan beneath Inner Barrier beach ridges appears to have formed as sea level rose. The water table in these barriers, rising with sea level, could have been the locus of deposition of humic colloids being translated downwards through the sand. The dates of 3,000–4,500 years B.P. near the top of the hardpan obtained from different localities do not refute this hypothesis. On the contrary, they support the view that sea level, with the water table at some elevation above, reached its present elevation somewhere between 3,000 and 5,000 years ago.

4. *Recent Standing Sea Level Stage.* During this period rivers have continued to alluviate their valleys, and estuaries such as that of the Lower Hunter have been greatly infilled. Sedimentation within embayments has been characterized by shoreline progradation. The Outer Barrier has formed by the accretion of multiple beach ridges which seems to have taken place in the early part of this period, probably under conditions of abundant sand supply in the nearshore zone. The gradual depletion of these supplies is a possible explanation for the cessation of accretion. A discussion of factors responsible for the later development of coastal dunes are beyond the scope of this paper.

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Explanation of Plates

Plate I

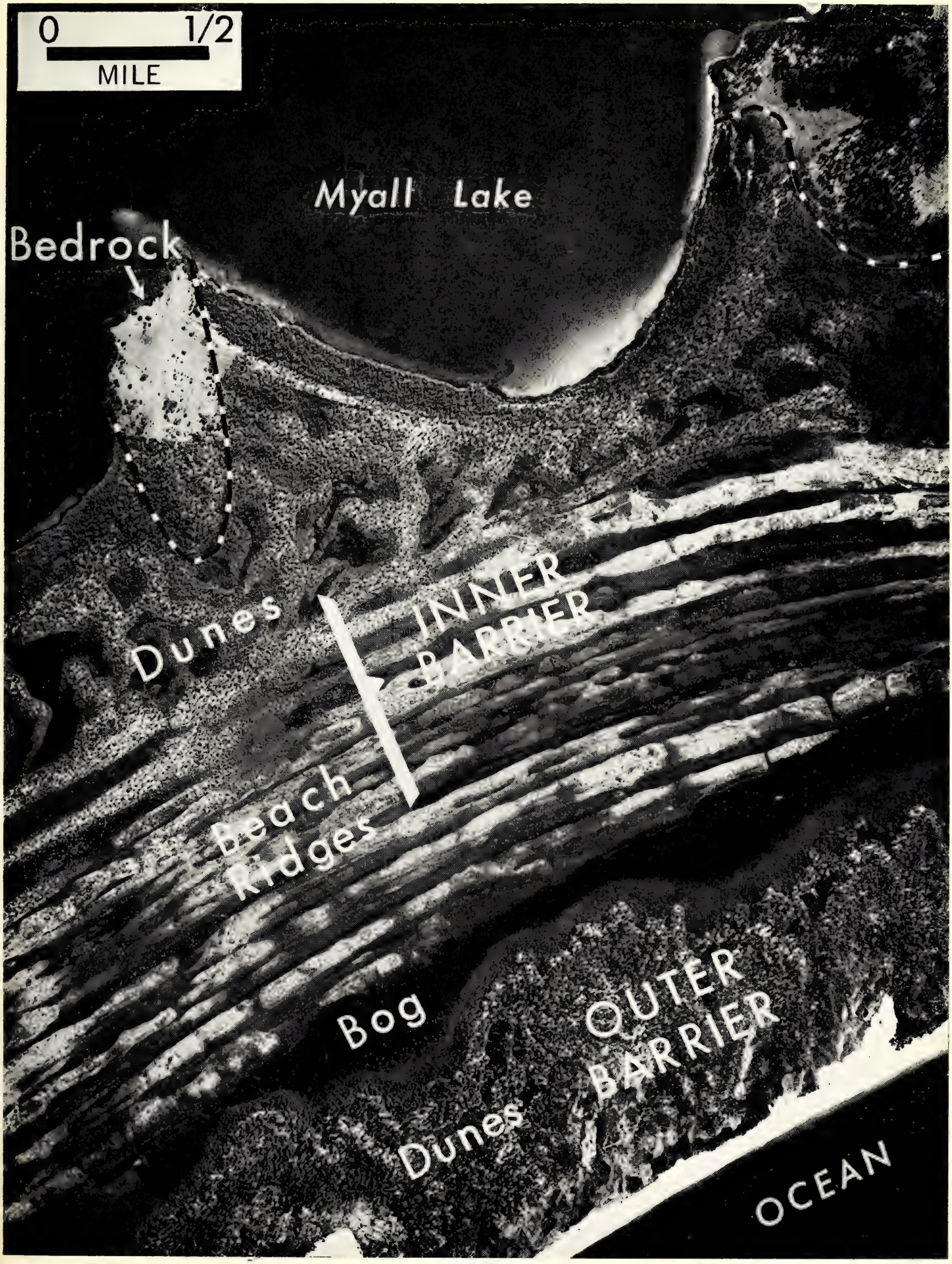
Aerial photograph of the Eurunderee embayment showing parabolic dunes of the Outer Barrier separated from Inner Barrier beach ridges and dunes by a freshwater bog. (Published with permission of N.S.W. Department of Lands.)

Plate II

Aerial photograph of the eastern end of Newcastle Bight embayment. The sheet of mobile sand is encroaching upon Outer Barrier beach ridges and stabilized dunes. A former phase of dune invasion is shown by a stabilized dune overlying beach ridges. (Published with permission of N.S.W. Department of Lands.)

Plate III

Upper Myall River in a steep-sided embayment. Pleistocene beach ridges have been truncated by the river, and swales have been entrenched. Sites of radiocarbon samples are shown. (Published with permission of N.S.W. Department of Lands.)


0 1/2
MILE
Myall Lake
Bedrock
Dunes
INNER BARRIER
Beach Ridges
Bog
OUTER BARRIER
Dunes
OCEAN


INNER
BARRIER
Tilligerry Creek
0 1/2
MILE
BARRIER
Beach Ridges
OUTER
Dunes
Mobile Sand
OCEAN


Bedrock
C-14 Date
Bombah Bog
C-14 Date
0 1/2
MILE

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The Stratigraphy of the Hervey Group in Central New South Wales

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Abstract—The outcrop distribution, structure, and stratigraphy of the sediments of the Hervey Group in Central New South Wales is outlined. These sediments were mainly deposited during the Upper Devonian although sedimentation probably started in the Middle Devonian and continued into the Lower Carboniferous. The Hervey Group is subdivided into three Sub-Groups called the Beargamil, Nangar and Cookamidgera Sub-Groups and the outcrop of these rocks is shown on seven geological maps.

Generally the basal sediments of the Hervey Group are characterized by red arkosic or lithic sandstones, and red siltstones and mudstones. These red measures have been grouped into the Beargamil Sub-Group and generally unconformably overlie Silurian to Lower Devonian acid volcanics, Middle Devonian granites or older Silurian and Ordovician sediments.

The Beargamil Sub-Group is overlain by a thick sequence of white quartzose sandstones, conglomerates, red siltstones and mudstones forming the Nangar Sub-Group. Red quartzose siltstones are the most abundant rock type and are interbedded with red and white quartzose sandstones, pebbly sandstones and conglomerates in a cyclic pattern. Upper Devonian fish-plates and plants are commonly preserved throughout the Nangar Sub-Group.

The Nangar Sub-Group reaches thicknesses of over 5,000 feet and is overlain by a thick sequence of red beds grouped into the Cookamidgera Sub-Group. These rocks mainly consist of red siltstones and red mudstones with minor amounts of red lithic and quartzose sandstones.

During the upper Middle Devonian to lower Upper Devonian, arkosic and lithic red beds were deposited on an alluvial plain which was flanked to the north-west and east by a shallow marine shelf and to the south by a landmass. In the Upper Devonian the sea regressed to the north and east and most of central New South Wales was an extensive alluvial flood plain. Rivers flowing from the west and then southwards around a land barrier to the south deposited quartzose sediments, silts and muds in the flood plain of large rivers and in large inland lakes. This style of sedimentation probably continued into the Lower Carboniferous with extensive deposition of fine-grained red silts and muds.

Introduction

During the Palaeozoic, Eastern Australia was the site for extensive sedimentation and volcanic activity. Deposition was interrupted by several periods of folding and granite intrusion, welding the Palaeozoic rocks onto the continental block by the end of the Palaeozoic. The oldest sediments of the Palaeozoic in New South Wales belong to the Cambrian Period and sedimentation continued into the Upper Devonian in the central, western, and southern part of New South Wales, and into the Permian in the northern and eastern part of New South Wales.

Hence the last period of sedimentation in the Palaeozoic of central western New South Wales occurred during the Upper Devonian. The Upper Devonian sediments of central western New South Wales are preserved in meridionally elongated outliers, normally lying on the eroded surface of folded older Palaeozoic rocks. In general, detailed stratigraphy is unknown and the fossil record is poor. Although the sediments are relatively poor in fossils, a marine fauna is common within the eastern area, while a fish fauna is characteristic of the western area. Lepidodendrid plants are scattered throughout all groups and in some areas, Archaeopterid and Rhacopterid plants may be representative of a Lower Carboniferous age (Conolly, 1964).

Upper Devonian rocks outcrop throughout eastern, central, and western New South Wales (Figs. 1 and 2). The Upper Devonian rocks of the Lachlan Geosyncline have been described (Conolly, 1964) and three broad provinces delineated. The rocks of the Lambie and Catombal Groups and the Upper Devonian rocks of the Yalwal-Eden district form the eastern province. The Mulga Downs and Cocoparra Groups form the western province and the Hervey Group the central province (Fig. 2).

In a preliminary report on the rocks of the Hervey Group, the author (Conolly, 1964) defined the Hervey group and suggested that it could be subdivided into three sequences which could be given Sub-Group status. These three Sub-Groups were not defined, since it was intended to define them and to discuss the stratigraphy in detail in this paper.

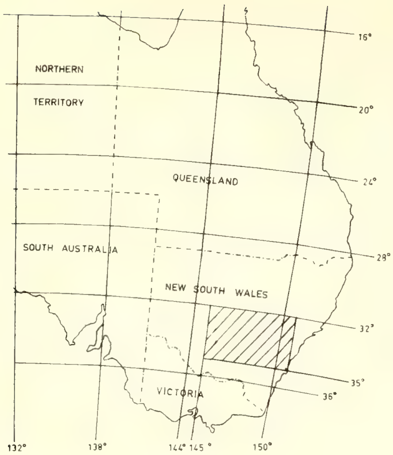


FIG. 1
Locality map showing area included in Fig. 2

Field investigations on the Upper Devonian sediments of central western New South Wales were started in March, 1958. From this time to November, 1959, the author studied the Upper Devonian sediments of the Catombal Group in the Wellington-Molong region (Conolly, 1960, 1963). From January, 1960, to February, 1962, field work was carried out on the other Upper Devonian sediments in central western New South Wales. Most of this latter period was spent mapping the Upper Devonian sediments of the Hervey Group which outcropped over a large area of central New South Wales (Figs. 2, 3).

Previous Investigations

Only three attempts have been made to form a concise account of the regional geology of the Condobolin-Peak Hill-Forbes district. In 1910, Andrews described the geology of the Forbes-Parkes goldfields and later in 1937, Raggatt published an account of the geology of the Condobolin-Trundle area. David and Browne (1950, pp. 249–250) described the Upper Devonian rocks from east and west of Forbes and Parkes, and gave the hitherto most complete account of the fauna and flora of these sediments.

Other brief notes published on the geology of central New South Wales have been made by Wilkinson (1885) who described the shallowly-dipping Upper Devonian ranges to the east of Parkes, and Dun (1898) who described Upper Ordovician graptolites from Peak Hill and also described the fossil assemblages of the Silurian and Devonian which are listed in Andrews' account of the Forbes-Parkes goldfield.

An account of the regional geology of the Forbes-Narromine military four mile area has been prepared by the author from knowledge of previous work and his investigations of the geology of the Bogan Gate-Trundle district, and the Forbes district.

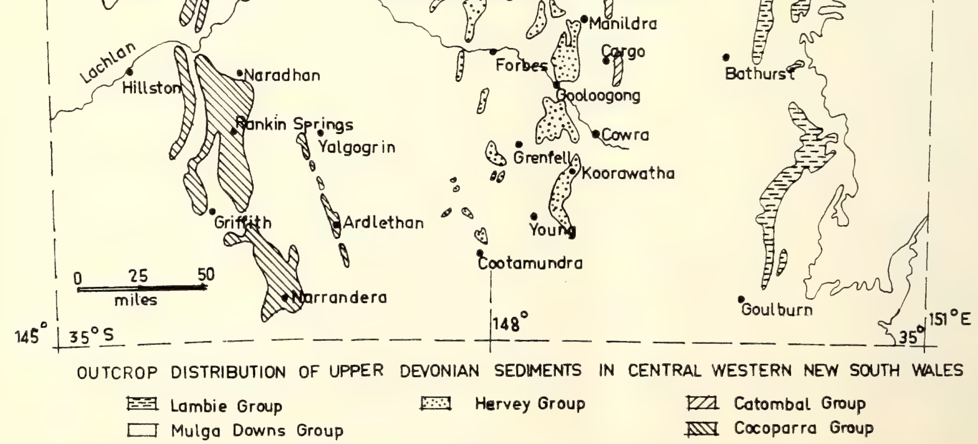


FIG. 2

The Geological succession at Forbes is :

TOP	Upper Devonian	Hervey Group
	?	Erosional gap
	Lower–? Middle Devonian 1,000′+	Massive sandstones with fragmentary fossils, including *Rhynchonella*, *Pterinaea*, *Pleurotomaria* and *Orthis* (Andrews, 1910, p. 25).
	Silurian 2,500′+	Interbedded shales, subgreywackes, limestones and conglomerates with *Halysites australe*, *Tryplasma*, *Heliolites*, *Favosites*, *Spongophyllum*.
	Upper Ordovician 1,500′+	Quartzose shales and laminated mudstones, often marly, grading into quartzose greywackes with turbidite structures. The Graptolites include species of *Climacograptus*.
BASE		

This succession has been measured in the anticlinal structures preserved immediately to the west of Forbes and previously mentioned by Andrews (**1910**, p. 23). The succession near Forbes appears to be quite conformable, although the Upper Devonian sandstones of the Hervey Group probably unconformably overlie the older rocks.

The sequence beneath the Upper Devonian represents a one-way trend from older deepwater to younger shallow-water marine shelf sediments in the Lower Palaeozoic. These sediments are often overlain by thick piles of acid volcanics, both to the east of Forbes in the Manildra district, and to the west in the Bogan Gate-Trundle district. In many localities acid lavas of this age unconformably underlie the Upper Devonian Hervey Group. To the east of the meridian of Parkes, the Lower Palaeozoic sequence thickens considerably and Steggles (**1961**) and Ringis (**1962**) have mapped areas to the north-east of the Hervey Syncline (Fig. 3) which show a thickness of over 25,000 feet of marine sediments, probably of Ordovician-Silurian age. A similar succession exists to the south of Mandagery railway station (Fig. 8), where there is a thick sequence of greywackes and shales. Hence there appears to be a shallowing of the sea to the west during the Lower Palaeozoic with shelf deposits being deposited in the Trundle-Forbes area and a deeper-water trough facies deposited to the east of Parkes, Forbes and Peak Hill.

Large areas of granitic rocks outcrop in central New South Wales and include the Yeoval Granite (Fig. 6), the Eugowra Granite (Figs. 8, 11) and the Young Granite (Fig. 13), which probably all belong to the one massif and intrude the Lower Palaeozoic sequence including the Lower Devonian acid lavas. Both the granites and older stratified rocks are unconformably overlain by Upper Devonian sediments. The age of the granites is provisionally placed as Middle Devonian. Small isolated granite masses also outcrop in the Condobolin-Bogan Gate district (Figs. 15, 17, 19) and may also be of Middle Devonian age.

Upper Devonian fish plates from the sediments of the Hervey Group have been described by Hills (**1932**, **1935**) and include *Bothriolepis*, *Phyllolepsis*, *Dipterus*, *Remingolepsis* ; from Gingham Gap in the Hervey Syncline ; and from Jemalong Gap west of Forbes, a very large dermal plate of *Bothriolepis*. Other recorded fossils (David and Browne, **1950**, pp. 249–250) include *Archaeocalamites* and *Lepidodendron australe* at Jemalong Gap, Calamitoid remains in the Corradgery Range near Jemalong Gap, Lepidodendroid remains from the Hervey Syncline and further south at Canowindra where they were associated with *Lingula gregaria*, marine fossils from Grenfell, and in the Trundle, Bogan Gate, Condobolin district marine fossils, including *Spirifer pittmani* at Mineral Hill, north-west of Condobolin.

Raggatt (**1937**) measured a section through the Devonian sediments in the Condobolin district and he also observed a similar sequence near Bogan Gate where he noted fossiliferous marine bands near the base. Raggatt also noted that the Devonian rested with marked unconformity on older metamorphics, rhyolites and fossiliferous limestones.

Structural Setting of the Hervey Group

The Hervey Group outcrops in three major synclinal belts which are elongated in a north-south direction. These belts include an eastern belt with many minor folds, a central belt called the Tullamore Syncline and a western belt called the Murda Syncline (Fig. 3).

The eastern belt has a total outcrop length of 140 miles and a maximum width of 24 miles from east of Parkes to Manildra but near its northern and southern extremities, the belt is only four to seven miles wide.

A similar large synclinal structure runs parallel to the eastern belt and at a distance of about 20 miles to the west of it. The northern half of this area is called the Tullamore Syncline

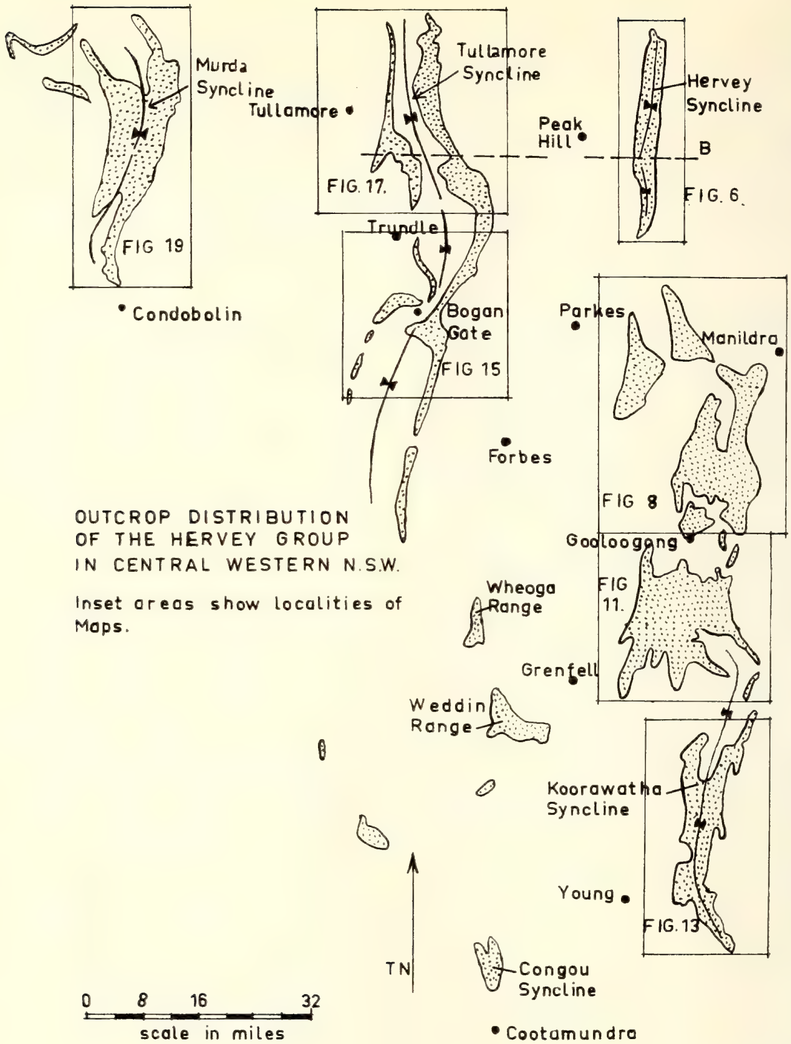


FIG. 3.

which is a very open structure extending from north of Tullamore at least 80 miles southwards towards Cootamundra. It has an average width of 10 miles in an east-west direction and may extend southwards to the Congou Syncline four miles to the north of Cootamundra.

A third synclinal structure occurs parallel to the Tullamore Syncline and at an average distance of 35 miles to the west of it. The structure has a thin southern nose to the north of Condobolin but broadens considerably to the north and has been called the Murda syncline.

There is no apparent link between these three synclinal belts except south of Grenfell where the Wheoga and Weddin Ranges sweep in an easterly direction towards the south-western portion of the Hervey Group at Grenfell. In this area the outcrops of both belts are only separated by a distance of twelve miles. The Weddin Range probably represents a broad anticlinal bend towards the eastern belt from the Tullamore Syncline.

These three broad synclinal structures are probably remnants of a large blanket of Upper Devonian sediment that was draped over the older Palaeozoic basement and has suffered broad warping and open folding. Extensive erosion has produced a flat plain where the three meridinal synclinal belts of Upper Devonian rocks outcrop above the older Palaeozoic basement rocks and Tertiary to Recent alluvial deposits.

TABLE 1

Stratigraphy of the Hervey Group (Upper Devonian–Lower Carboniferous) in Central New South Wales

	Hervey Syncline	Parkes-Manildra	Gooloo-gong-Grenfell	Koora-watha Syncline	Weddin Range	Tullamore	Trundle-Bogan Gate	Murda Syncline
COOKAMIDGERA SUB-GROUP Upper red beds ..	Burrill Fm.	Undifferentiated Eurow Fm.	Undifferentiated	Koorawatha Fm.	Not exposed	Undifferentiated	Undifferentiated	Belvedere Fm.
NANGAR SUB-GROUP Rhythmic succession of white sandstones with red sandstones and red siltstones	Caloma S.S. Pipe Fm. Mandagery S.S.	Bumberry Fm. Pipe Fm. Mandagery S.S.	Bumberry Fm. Mandagery S.S.	Bumberry Fm. Mandagery S.S.	Not exposed Weddin S.S.	Weddin S.S. Cloghnan Shale Troffs Fm.	Weddin S.S. Cloghnan Shale Troffs Fm.	Boona S.S.
BEARGAMIL SUB-GROUP Basal red beds, lithic sandstones, arkoses	Kadina Fm. Clagger S.S.	Kadina Fm.	Hunter Siltstone Peaks S.S. with Mogongong Congl. Member	Bendick Fm.	Bogan Gate S.S.	Not exposed	Bogan Gate S.S.	? Condobolin Fm.

Outline Stratigraphy of the Hervey Group

The type section of the Hervey Group was defined by Conolly (1964). The type section was measured along Clagger Creek to the Caloma Trig, six miles north-east of Hervey Park at the northern end of the Hervey's Range (Fig. 6). The section here is 5,250 feet thick and consists of the following subdivisions :

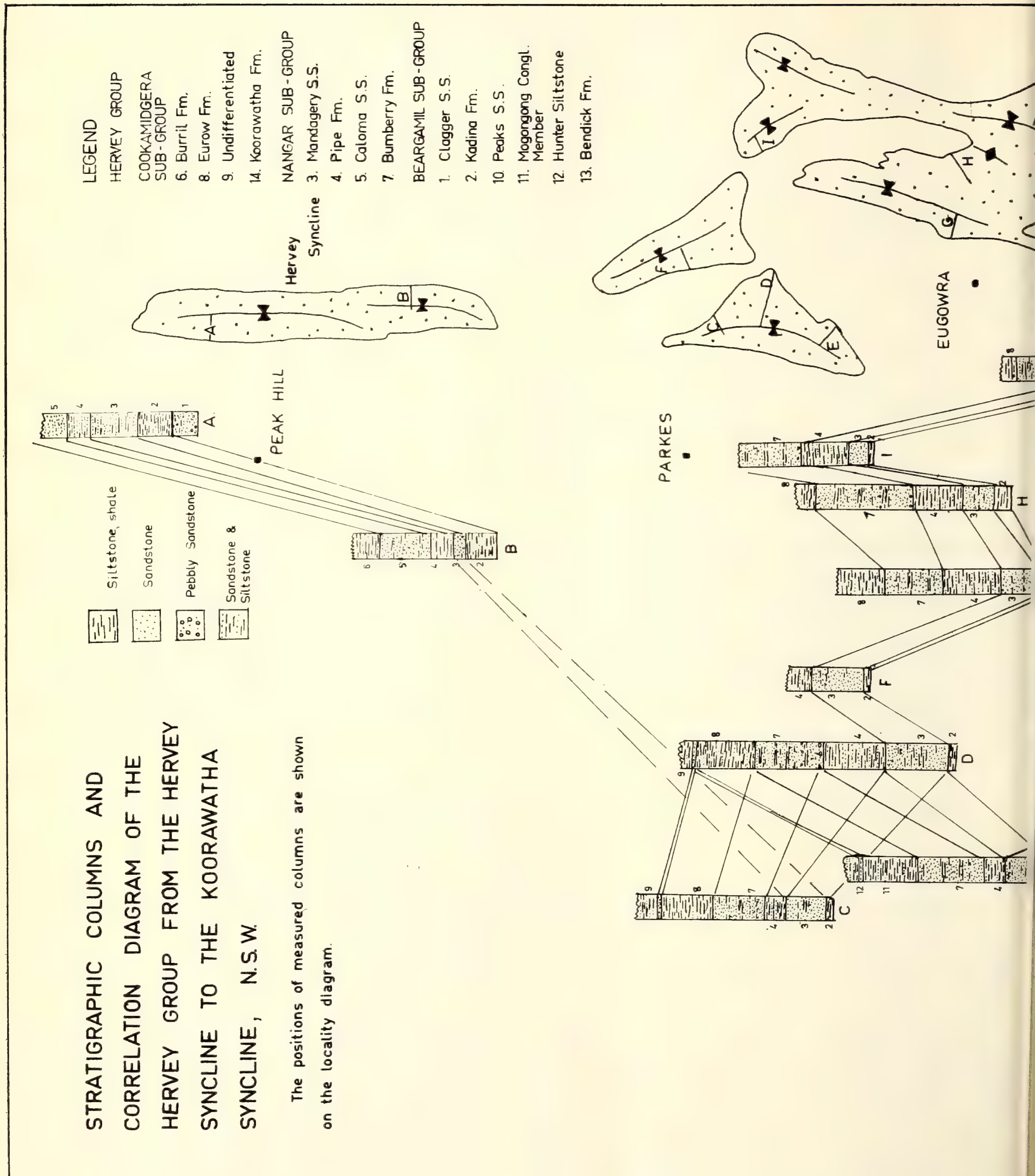
			Thickness in Feet
TOP			
Nangar Sub-Group	Caloma Sandstone	White orthoquartzites, forming rugged cliff outcrops	750′+
	Pipe Formation	Green and red shales and siltstones with occasional white sandstone members	820′
	Mandagery Sandstone	White sandstones interbedded with red siltstones and occasional red sandstones	1,720′
Beargamil Sub-Group	Kadina Formation	Red siltstones with red sandstone members ..	1,110′
	Clagger Sandstone	Thin conglomerates at the base going into massive red and green sandstones and siltstones	850′
		TOTAL	5,250′+
BASE			

At this locality, the Hervey Group is separated from older Palaeozoic andesites to the west by a thin strip of boulder drift and alluvium. On the north-eastern side and in the southern section of the Hervey's Range, the Upper Devonian overlies acid volcanics of probable Lower Devonian age with a slight unconformity. The Caloma Sandstone, Pipe Formation and Mandagery Sandstone belong to the Nangar Sub-Group and the Kadina Formation and Clagger Sandstone to the Beargamil Sub-Group. The Cookamidgera Sub-Group is not preserved in this area but occurs in the southern half of the Hervey's Range which is downfaulted against the northern half (Fig. 6).

The Hervey Group outcrops discontinuously over an area of over ten thousand square miles (Fig. 2). Variations in total thickness over this area are only apparent because of extensive erosion of the upper formations. Correlation becomes difficult because of the large erosional gaps and facies changes, resulting in the erection of numerous formational names which are shown on the correlation chart (Table 1) and on the correlation diagrams (Figs. 4 and 5).

THE BEARGAMIL SUB-GROUP

The type section was measured one half mile due east of Beargamil Dam on the western flank of the Bumberry Syncline (Fig. 8). In



STRATIGRAPHIC COLUMNS AND CORRELATION DIAGRAM OF THE HERVEY GROUP FROM THE HERVEY SYNCLINE TO THE KOORAWATHA SYNCLINE, N.S.W.

The positions of measured columns are shown on the locality diagram.

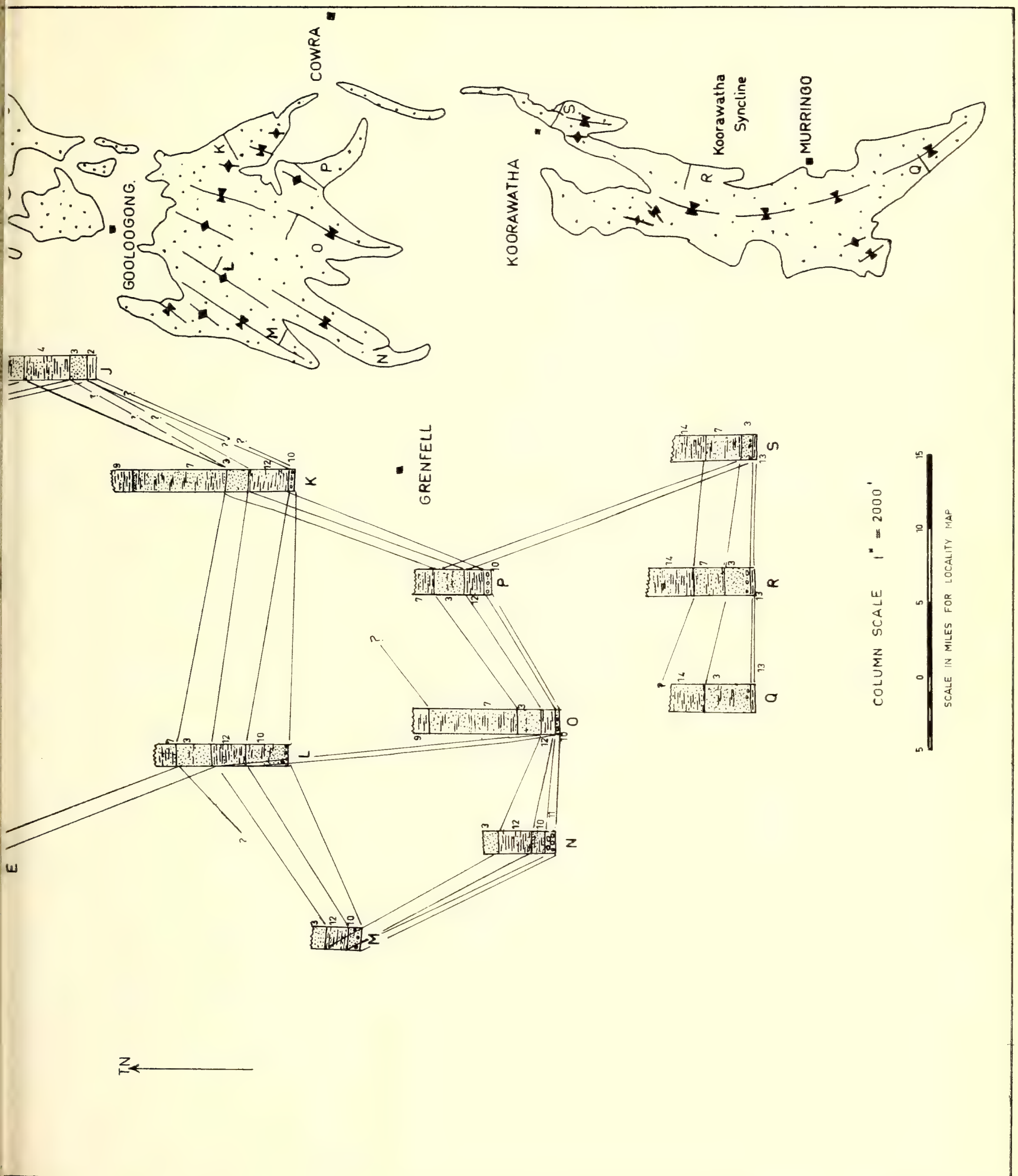
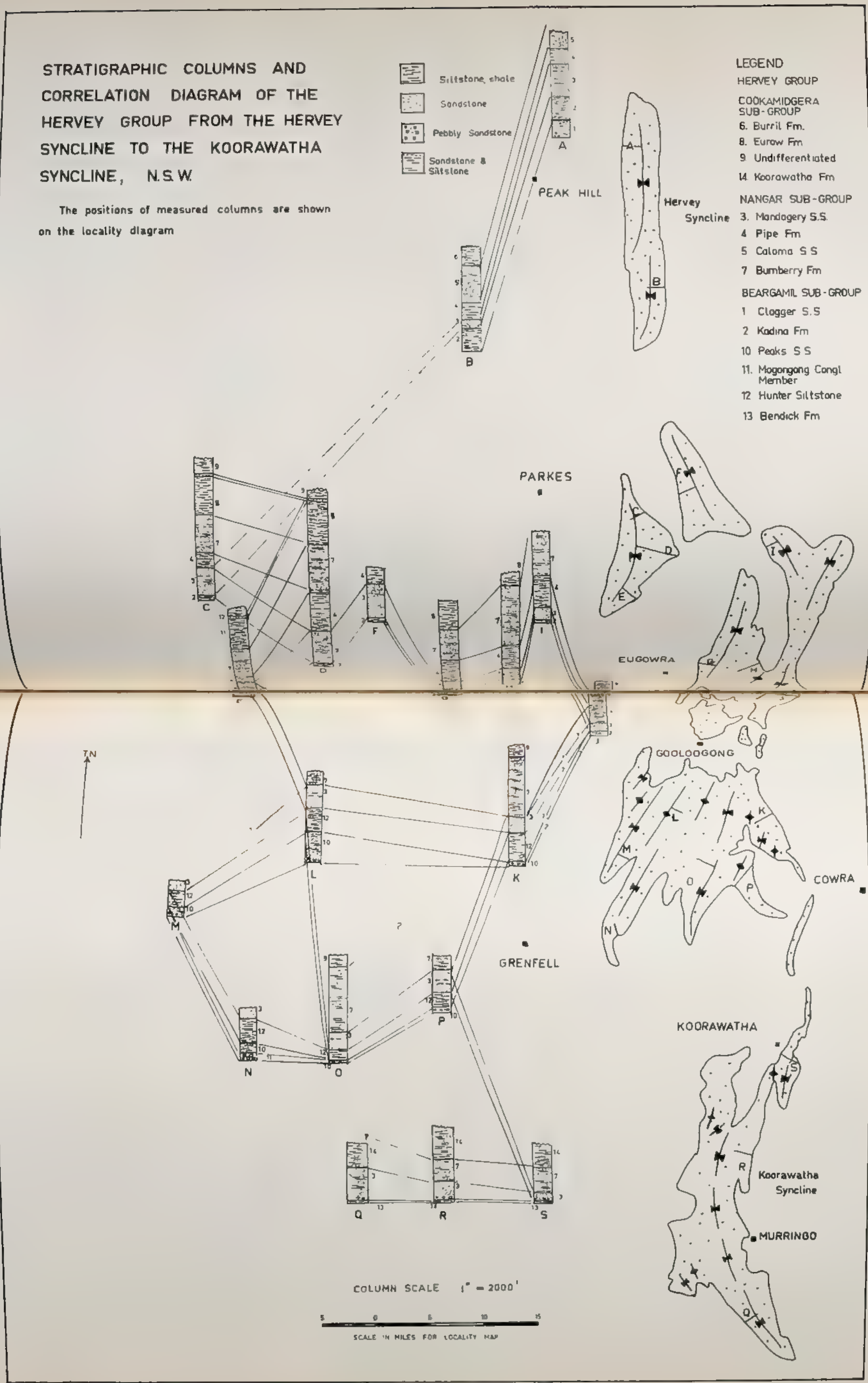

COWRA
GOOLOOGONG
KOORAWATHA
Koorawatha Syncline
MURRINGO
GRENFELL
COLUMN SCALE 1" = 2000'
SCALE IN MILES FOR LOCALITY MAP
N

Fig. 4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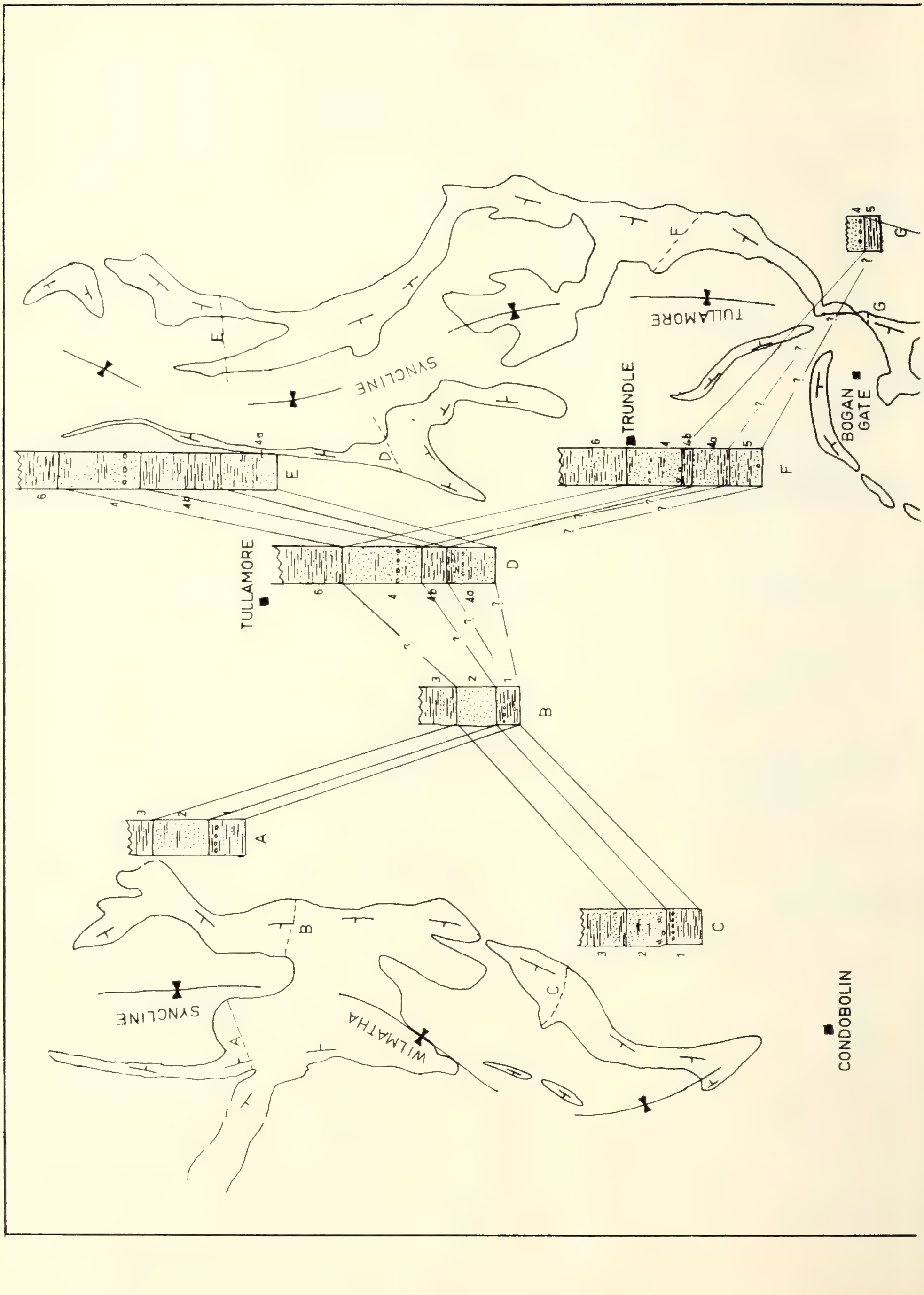
The positions of measured columns are shown on the locality diagram
Siltstone, shale
Sandstone
Pebbly Sandstone
Sandstone & Siltstone
LEGEND
HERVEY GROUP
COOKAMIDGERA SUB-GROUP
6. Burril Fm.
8. Eurow Fm
9 Undifferentiated
14 Koorawatha Fm
NANGAR SUB-GROUP
3. Mandagery S.S.
4 Pipe Fm
5 Caloma S S
7 Bumberry Fm
BEARGAMIL SUB-GROUP
1 Clogger S.S
2 Kadina Fm
10 Peaks S S
11. Mogongong Congl Member
12 Hunter Siltstone
13 Bendick Fm
PEAK HILL
Hervey Syncline
PARKES
EUGOWRA
GOOLOOGONG
COWRA
GRENFELL
KOORAWATHA
Koorawatha Syncline
MURRINGO
T.N
COLUMN SCALE 1" = 2000'
SCALE IN MILES FOR LOCALITY MAP

FIG. 4


TULLAMORE
TRUNDLE
BOGAN GATE
CONDOBOLIN
SYNCLINE
TULLAMORE
SYNCLINE
WILMATHA
A
B
C
D
E
F
G

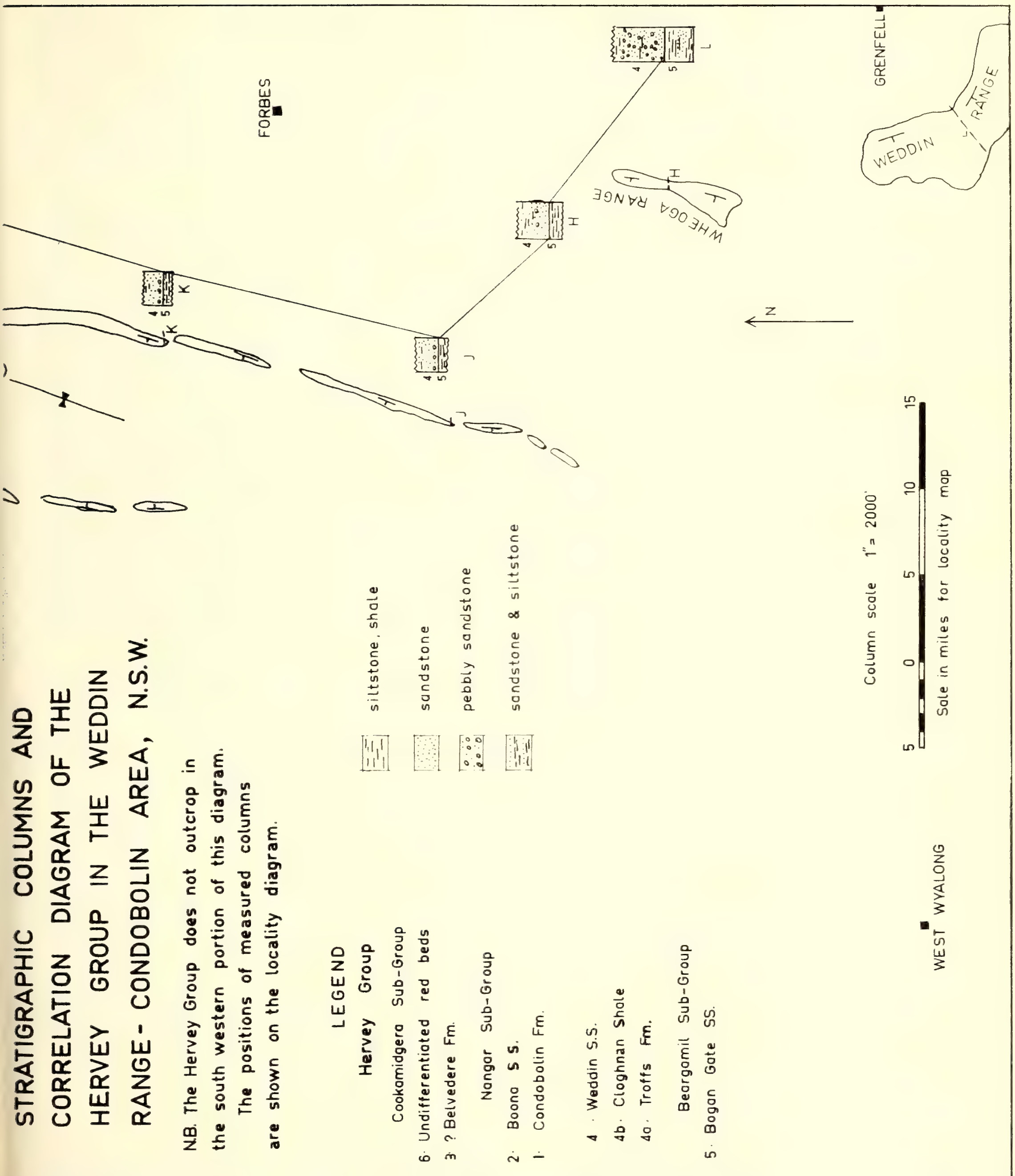

STRATIGRAPHIC COLUMNS AND CORRELATION DIAGRAM OF THE HERVEY GROUP IN THE WEDDIN RANGE - CONDOBOLIN AREA, N.S.W.
N.B. The Hervey Group does not outcrop in the south western portion of this diagram.
The positions of measured columns are shown on the locality diagram.
LEGEND
Hervey Group
Cookamidgera Sub-Group
6· Undifferentiated red beds
3· ? Belvedere Fm.
Nangar Sub-Group
2· Boona S.S.
1· Condobolin Fm.
4 · Weddin S.S.
4b· Cloghnan Shale
4a· Troffs Fm.
Beargamil Sub-Group
5· Bogan Gate SS.
siltstone, shale
sandstone
pebbly sandstone
sandstone & siltstone
Column scale 1" = 2000'
5 0 5 10 15
Sale in miles for locality map
WEST WYALONG
FORBES
GRENFELL
WEDDIN
RANGE
WHEOGA RANGE
N
K
J
H
L
4
5

Fig. 5

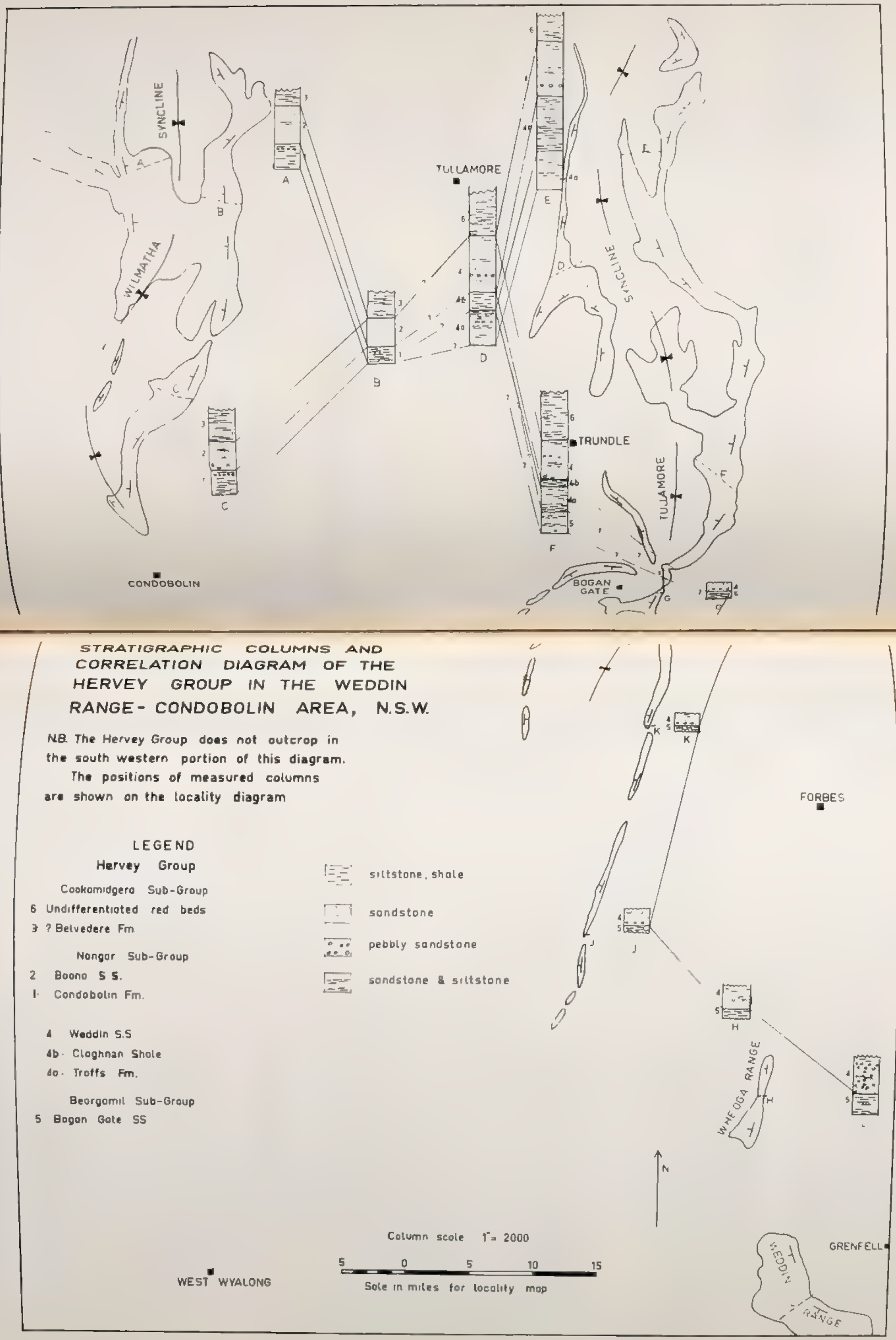

STRATIGRAPHIC COLUMNS AND CORRELATION DIAGRAM OF THE HERVEY GROUP IN THE WEDDIN RANGE - CONDOBOLIN AREA, N.S.W.
N.B. The Hervey Group does not outcrop in the south western portion of this diagram. The positions of measured columns are shown on the locality diagram
LEGEND
Hervey Group
Cookamidgera Sub-Group
6 Undifferentiated red beds
3 ? Belvedere Fm.
Nangar Sub-Group
2 Boona S.S.
1 Condobolin Fm.
4 Weddin S.S
4b Cloghnan Shale
4a Troffs Fm.
Beargamil Sub-Group
5 Bogan Gate SS
siltstone, shale
sandstone
pebbly sandstone
sandstone & siltstone
Column scale 1" = 2000
5 0 5 10 15
Scale in miles for locality map
SYNCLINE
WILMATHA
TULLAMORE
TRUNDLE
SYNCLINE
TULLAMORE
CONDOBOLIN
BOGAN GATE
FORBES
WHEOGA RANGE
GRENFELL
WEDDIN RANGE
WEST WYALONG
N

FIG. 5

this locality two to three hundred feet of basal red conglomerates, red arkoses and lithic sandstones rest with a marked angular unconformity on acid volcanics and tuffs of probable Lower Devonian age.

The basal red beds and arkoses of this Sub-Group make one of the most distinctive features of the Hervey Group. Elsewhere to the east in both the Catombal Group and the Lambie Group, the basal beds are normally of marine origin with numerous fossiliferous bands containing brachiopods.

To the south-west of the Hervey Group, the Cocoparra Group is marked by the presence of basal red measures, but they are characteristically conglomeratic, hence can be distinguished from the finer red beds of the Beargamil Sub-Group. To the west the Mulga Downs Group is generally similar to the Cocoparra Group and overlies the marine beds of the Ampitheatre Group (Rayner, 1962).

The Nangar Sub-Group

The type section of the Nangar Sub-Group was measured in the vicinity of the Nangar Trig. on the axis of the Nangar Anticline to the west of Manildra (Fig. 8).

This Sub-Group generally comprises more than four fifths of the total thickness of the Hervey Group and consequently is the unit that is the most typical of Hervey Group sedimentation. It always begins with a massive orthoquartzite sandstone formation which lies above the upper red beds of the Beargamil Sub-Group. Following this, there is a rhythmic sequence of red and white formations. The sedimentation appears to be cyclic with the following characteristic cycle :

Top	Red shales and siltstones
	Red siltstones with red sandstones
	Red siltstones with red and white sandstones
Base	White sandstones

The thickness of such a cycle may be 100 feet or over a thousand feet. Formations within the Sub-Group may have several such cycles of sedimentation or may correspond to one major cycle.

The Cookamidgera Sub-Group

The type section was measured immediately east of the village of Cookamidgera in the centre of the Parkes Syncline, fifteen miles to the east of Parkes (Fig. 8). The horizons above the highest massive white sandstone in the Nangar Sub-Group consist of a thick sequence of red beds which have been called the Cookamidgera Sub-Group. Because of their fine-grained nature, they make poor outcrops and because of their position in the sequence, they frequently fail to outcrop.

The upper red-bed sediments of the Upper Devonian have also been recognised in the Cocoparra, Catombal and Lambie Groups (Conolly, 1964). Upper red beds preserved in the centre of open synclines may only correspond to the red-measure phase within a typical Nangar Sub-Group cycle. However, when lithological correlation can be made on a local scale, red-measure rhythms of this type can be given Formation or Sub-Group status.

DETAILED STRATIGRAPHY OF THE HERVEY GROUP

Since the Hervey Group outcrops in isolated synclinal areas and correlation becomes difficult when erosional gaps separate different sequences, each area with its own local rock units will be described separately.

In this way, the Hervey Group can be subdivided into eight different areas of outcrop that correspond to natural structural features separated from one another by older Palaeozoic rocks or alluvium. Sometimes correlation can be made between areas but only a few formations persist over large distances. The stratigraphy of the Hervey Group in the eight areas is shown on Table 1, and the correlation diagrams (Figs. 4 and 5) show the areal relationships of the formations.

There are seven geological maps showing the outcrop of the Hervey Group (Figs. 6, 8, 11, 13, 15, 17, 19), covering the areas shown on Fig. 3. The stratigraphy of the areas listed on Table 1 will be described in the following order :

1. Hervey Syncline (Fig. 6)
2. Manildra-Gooloogong district (Fig. 8)
3. Gooloogong-Grenfell district (Fig. 11)
4. Koorawatha Syncline (Fig. 13)
5. Tullamore-Weddin Range district (Figs. 15, 17)
6. Murda Syncline (Fig. 19)

The Weddin Range, Tullamore, Trundle-Bogan Gate districts listed on Table 1 are more conveniently described under the heading " Tullamore-Weddin Range district ".

The Hervey Syncline

The Hervey Syncline is a long narrow synclinal structure elongated in a north-south direction, occurring several miles to the east of Peak Hill (Fig. 6). Detailed stratigraphy and structure are shown on the geological map of the Hervey Syncline (Fig. 6).

The geological map has been prepared from air photos and ground traverses on a planimetric base at a scale of 1 : 45,000. The Hervey Syncline forms a basin-shaped range with the inner depression of the basin coinciding with the synclinal axis. The outer sides are made up of rugged cliffs of sandstone which rise to a height of 1,800 feet above the flat alluvial plain to the west of Peak Hill. The highest point is the Trig-station at Caloma in the northern end of the range which is over 2,600 feet above sea level (Plate 1).

The Hervey Syncline is essentially two large synclines belonging to the one synclinal structure which are faulted against one another by a steeply dipping normal fault with a downthrow side to the south east. Near Kadina Creek this fault has its maximum displacement, where older Palaeozoic formations rest against upper Hervey Group formations. Faulting also occurs on the north-western nose where several small cross faults allow for the accommodation of thick basal formations that dip more steeply under the upper formations (Fig. 6).

The stratigraphy of the Hervey Group in the Hervey Syncline will be described by discussing each formation in the following order :

Base	1. Clagger Sandstone	Beargamil Sub-Group
	2. Kadina Formation	
	3. Mandagery Sandstone	Nangar Sub-Group:
	4. Pipe Formation	
	5. Caloma Sandstone	
Top	6. Burrill Formation	Cookamidgera Sub-Group

The Clagger Sandstone

The Clagger Sandstone is the basal formation of the Hervey Group in the Hervey Syncline. It can be defined as a sequence of basal sediments which consist of red sandstones and pebbly sandstones and a smaller percentage of red shales and siltstones. When the top of the formation is reached, finer red siltstones become the dominant sediment, the last thick (five to ten feet) red sandstone member being defined as the top horizon conformably underlying the fine red siltstones and shales of the Kadina Formation.

Basal red shales and thin pebbly sandstones of the Clagger Sandstone unconformably overlie acid volcanics of probable Lower Devonian age in the northern section of the Hervey Syncline. The Clagger Sandstone thins considerably to the south and lenses out completely several miles to the south of Gingham Gap. The beds of the Clagger Sandstone are poorly preserved, but they form high strike ridges around the northern nose of the Hervey syncline near Clagger Creek where the type section was measured, as follows :

Top	Interbedded red sandstones, white sandstones and red siltstones	200′
	Red sandstones more abundant than red siltstones with which they are interbedded	440′
	Fine grained red conglomerate and coarse sandstone	30′
Base	Red siltstones with minor sandstone and pebbly sandstone lenses	180′
	Total	850′

The most characteristic feature of the sediments of the Clagger Sandstone is their red colour and poorly sorted nature. Sedimentary structures include current bedding which occurs in bands two inches to three feet thick, ripple marks of both wave and current types, and mud-cracks. Bedding tends to be lenticular and individual members cannot be traced for great distances. No fossils have been found or recorded from the Clagger Sandstone. This may be merely a function of poor conditions of preservation prevailing during deposition, particularly in an oxidising environment where carbonaceous remains are quite often destroyed.

The Kadina Formation

The Kadina Formation overlies the Clagger Sandstone to the north of Gingham Gap but when the Clagger Sandstone lenses out to the south, it forms the basal formation of the Hervey Group (Fig. 6). It is defined as a thick sequence of fine-grained red sediments which are mostly red siltstones with minor shales and very few sandstone members which are also red in colour. The type section occurs in the vicinity of the Kadina Trig. station, distance four miles north of the southern tip of the Hervey Syncline, where the following sequence was measured :

Top	Red siltstones with minor fine-grained red sandstones	450′
	Red siltstones	100′
Base	Erosional gap, with traces of red siltstone	? 500′
	Total Thickness	approx. 1,050′

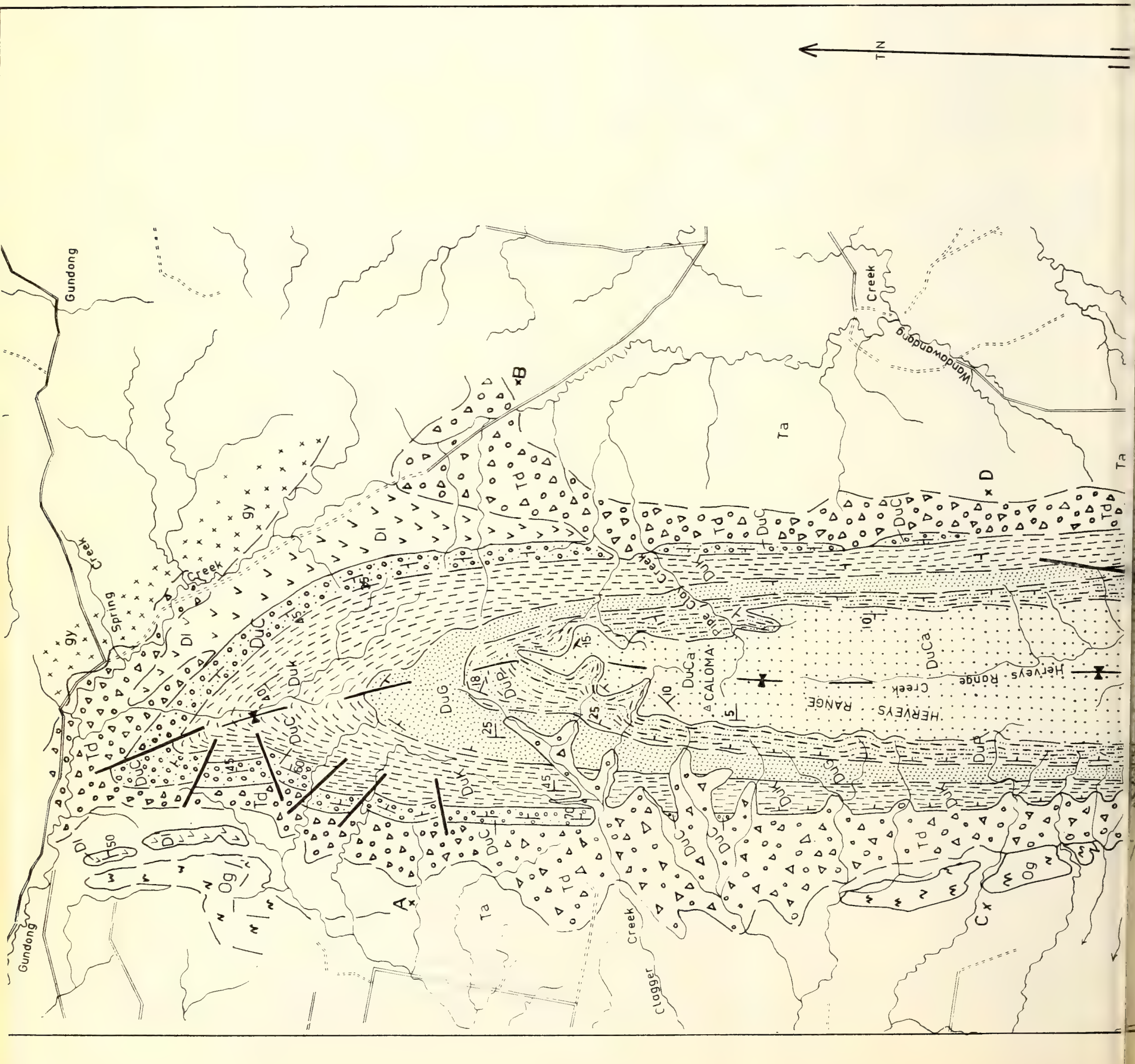
The Kadina Formation has a consistent thickness throughout most of the Hervey Syncline. In the north a thickness of 1,110 feet was measured along Clagger Creek. The Kadina Formation may be considerably thicker in the northern nose of the Hervey Syncline, two miles south of Gundong Creek; however, there is a lot of minor folding and faulting in this region making it impossible to calculate the thickness accurately.

Once again fossils have not been recorded or found in the Kadina Formation. The top of the Kadina Formation coincides with the base of the first massive white sandstone member of the Mandagery Sandstone which conformably overlies it. Sedimentary structures include ripple marks, small scale current bedding, " worm tracks " and mudcracks.

THE MANDAGERY SANDSTONE

Mr. D. B. Walker (personal communication) first used the name Mandagery Sandstone for the Upper Devonian sediments that outcrop in the vicinity of Mandagery Station east of Parkes (Fig. 8). Although Walker's facts were recorded on an unpublished geological map the term " Mandagery Sandstone " has been frequently used by geologists when reference is made to the Upper Devonian sandstones that outcrop in the ranges to the west of Manildra.

Since one of the most striking features of the Upper Devonian sediments of this region are cliff-forming sandstones it seems appropriate to place these sandstones into a formation called the

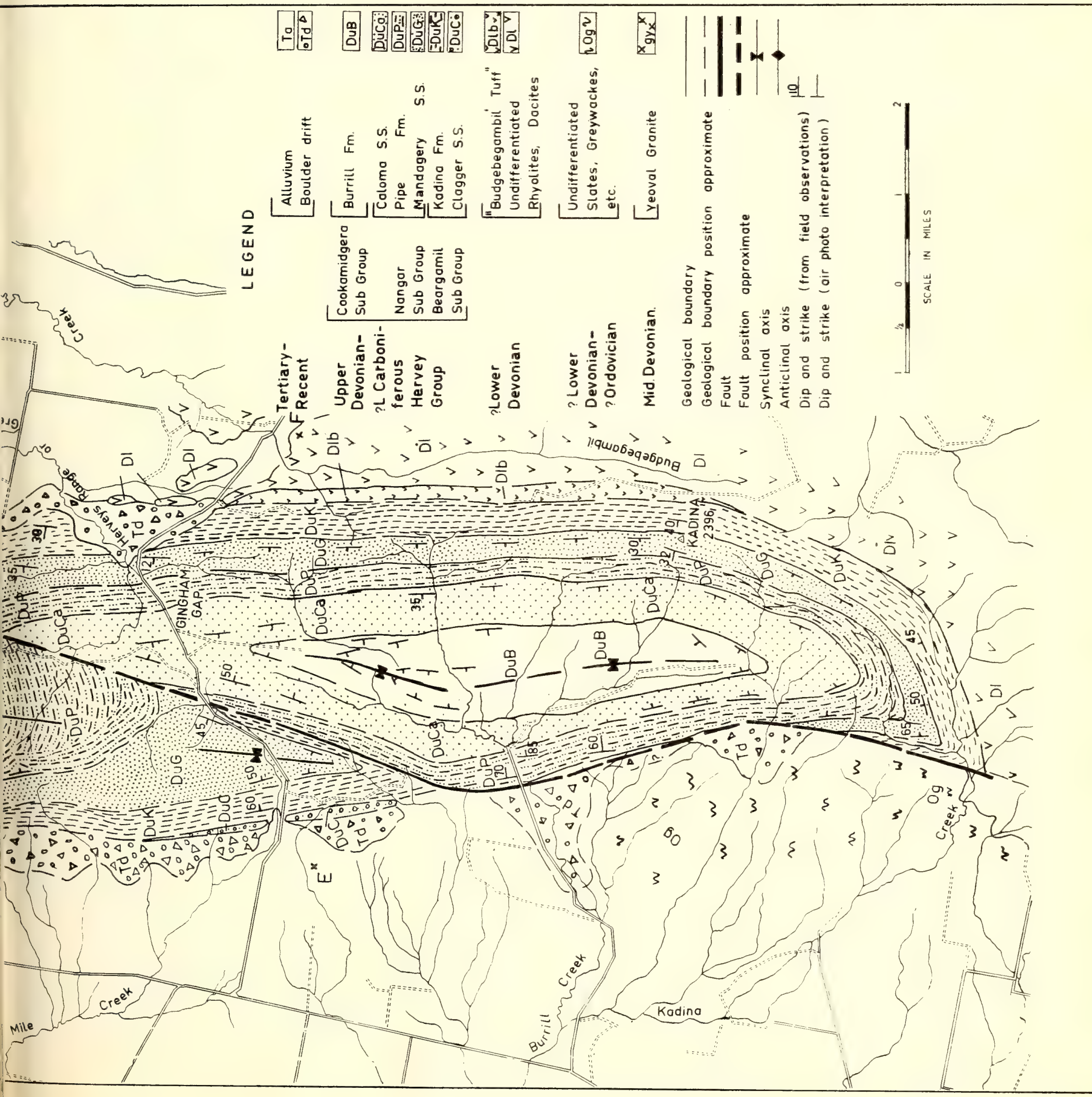


Mandagery Sandstone which has a type section in the Mandagery district. This type section will be described in detail in the next section which discusses the geology of the Manildra-Gooloogong region.

In the Hervey Syncline the Mandagery Sandstone conformably overlies the Kadina Formation and consists of fine-grained to coarse-grained white sandstones which are interbedded with red and green shales and siltstones. Red sandstones do occur but are not abundant. A section measured in the Gingham Gap area along the road to Baldry from Peak Hill on the eastern side of the Hervey Syncline has the following sequence:

Top	White sandstones with fine-grained siltstone	150′
	White massive sandstone	100′
Base	Interbedded white sandstones and shales with some red sandstone	200′
	Total Thickness	450′

Near the Kadina Trig. station the Mandagery Sandstone consists of 200 feet of interbedded



GEOLOGICAL MAP SHOWING THE HERVEY GROUP IN THE HERVEY SYNCLINE

Fig. 6

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BASE	Interbedded white sandstones and shales with some red sandstone	200′
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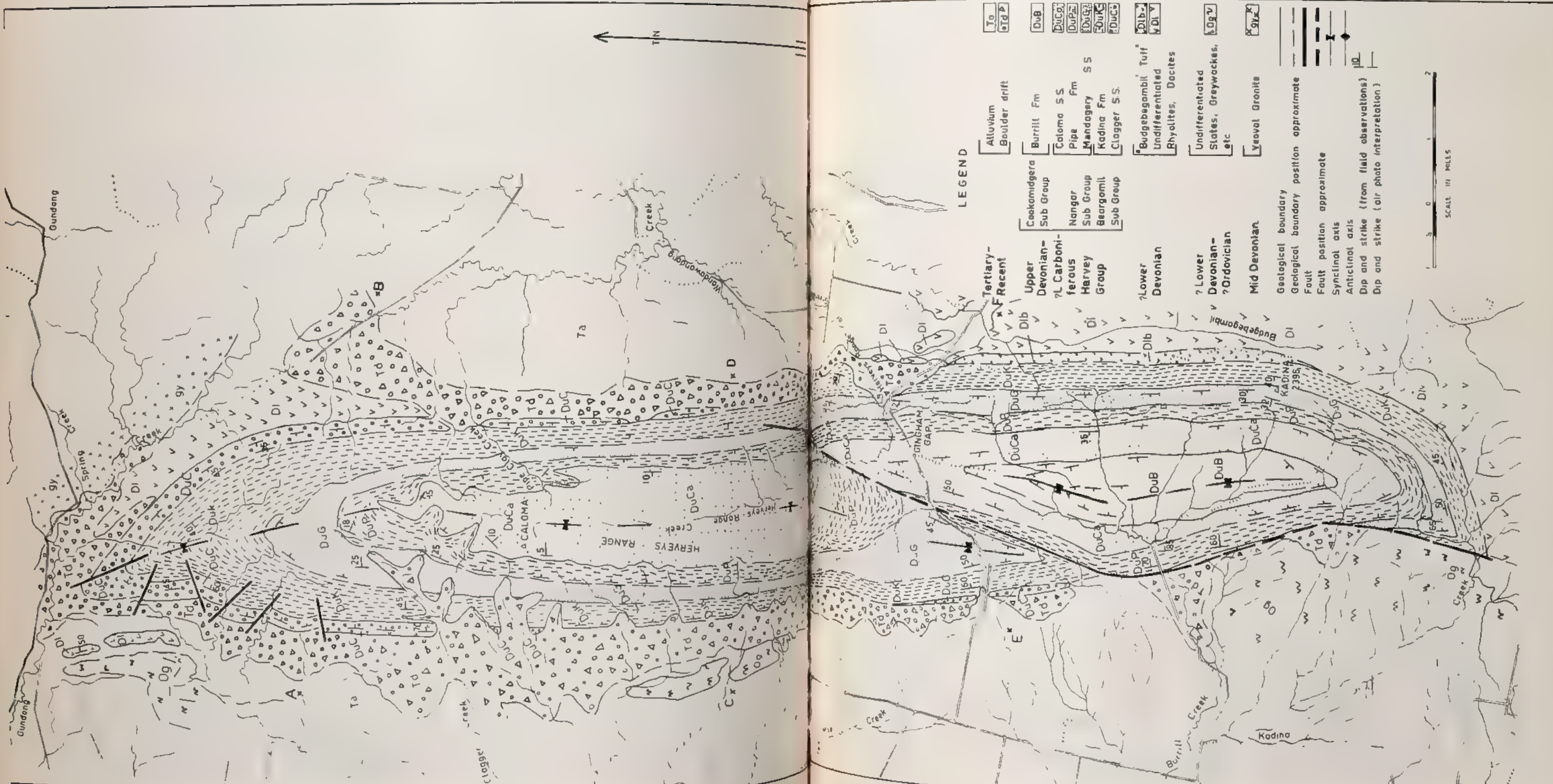
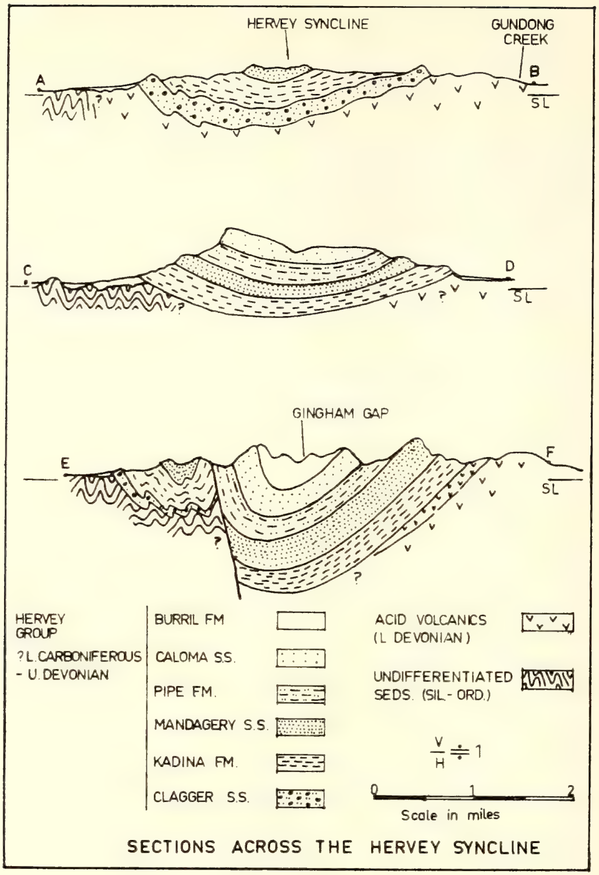


GEOLOGICAL MAP SHOWING THE HERVEY GROUP IN THE HERVEY SYNCLINE

FIG. 6



SECTIONS ACROSS THE HERVEY SYNCLINE

Fig. 7

white sandstones and white sediments overlain by 150 feet of massive sandstone that forms a prominent ridge line, that strikes northward towards Gingham Gap.

The Mandagery Sandstone marks the beginning of the Nangar Sub-Group which is a rhythmic succession of white and red sediments. The rhythmic nature of the sequences within the Nangar Sub-Group makes many of the formations within it hard to define. For instance, in the northern part of the Hervey Syncline the Mandagery Sandstone has many more beds of fine-grained sediments normally red in colour, interbedded among the more massive pale-coloured or white sandstones. The thickness in the Clagger Creek section (Flg. 6) is 1,720 feet, most of which is sandstone, but the sequence consists of at least twelve cycles of white sandstone separated by finer-grained green siltstones and shales.

The top of the Mandagery Sandstone is the last white sandstone member which conformably underlies several hundred feet of fine-grained sandstones, shales and siltstones of the Pipe Formation. Impressions of fish plates and lepidodendrid plants have been found in the Mandagery Sandstone in the Clagger Creek section, but this formation is not as rich in fossils as the Caloma Sandstone some one thousand feet stratigraphically above it. Sedimentary structures include current bedding, ripple marks and occasionally small flow and load casts are preserved on the base of sandstone bands overlying finer sediments.

The Pipe Formation

The Pipe Formation consists of fine-grained sediments that make poor outcrops and occurs conformably between two formations that contain a higher percentage of sandstone, the Mandagery Sandstone and the Caloma Sandstone. The Pipe Formation can be easily traced on aerial photographs because it outcrops in valleys between the sandstone ridges of the Caloma and Mandagery Sandstone.

The formation consists of very fine-grained white sandstones with red and white siltstones and red and green or buff shales. The type section was measured in the vicinity of the Caloma Trig. station in the northern end of the Hervey Syncline about one mile to the west of the headwaters of Pipe Clay Creek which derives its name from the clays and silts of the Pipe Formation (Fig. 6). In this region the following section was measured :

Top	Fine-grained white sandstones and siltstones with green shales	250′
	Red and white siltstones with some fine-grained white sandstone	350′
Base	Mainly very fine-grained sediment, red and white siltstones and some fine to medium-grained white sandstones towards the base	320′
	Total Thickness	820′

In the southern part of the Hervey Syncline a section has been measured where Burrill Creek crosses the western faulted limb of the Hervey Syncline. Here, there is a fairly large thickness of fine and medium-grained sandstone at the base of the formation making a subdued ridge line and the beds are very steeply dipping and locally overturned.

Close to the Kadina Trig. station the Pipe Formation forms a prominent valley and is approximately 750′ thick. Most of the sediment consists of fine-grained red and white sandstones and coarse-grained red siltstones. Sedimentary structures include ripple marks and small-scale cross bedding.

The Caloma Sandstone

The Caloma Sandstone conformably overlies the Pipe Formation and is a massive sandstone formation consisting of medium to fine-grained white sandstones with many thin pebbly or conglomerate layers. It forms large cliffs capping the Hervey Syncline and making a very prominent ridge line throughout the Hervey Syncline (Plate 1). The type section was measured in the vicinity of the Caloma Trig. station in the northern end of the Hervey Range where the Caloma Sandstone has a thickness of at least 750′. In this locality the top of the formation is missing due to erosion, but the preserved thickness of the formation increases towards Gingham Gap. South of Gingham Gap, the Caloma Sandstone is conformably overlain by a sequence of red beds grouped into the Burrill Formation. In a section measured near Kadina Trig. station in the southern part of the Hervey Syncline the Caloma Sandstone consists of 1,720 feet of white sandstones with several fish-plate horizons which occur at interavls throughout the succession.

Hills (1932) has described fish plates that occur in the Caloma Sandstone in the Gingham Gap area. He described *Phyllolepis* sp., *Remingolepis* sp., *Striacanthus* sp., *Bothriolepis* sp., *Antiarchi* gen indet., *Holoptychius* sp., and Crossopterygii gen indet., and later in 1935 Hills described plates related to the genus *Dipterus*. Hills ascribes to this fauna an Upper Devonian age, comparable with that of similar faunas in Europe. The writer has also found many poorly preserved fish plates in the type area near Caloma Trig. and these are frequently associated with *Lepidodendron australe*. The fish plates generally occur in pebbly bands in medium-grained white sandstones. Quite often only one or two fish plate impressions will be found over a very large area and they are frequently poorly preserved.

Current bedding is the dominant sedimentary structure in the Caloma Sandstone and units from two to three feet thick are quite abundant.

The Burrill Formation

The Burrill Formation is a red-bed sequence that conformably overlies the massive white sandstones of the Caloma Sandstone. It is not preserved to the north of Gingham Gap but in the southern part of the Hervey's Range outcrops as a synclinal structure about four miles long and one mile across at its maximum width (Fig. 6). The beds of the Burrill Formation consist mainly of medium to coarse-grained red siltstones, but there are also many red sandstone members, particularly towards the base.

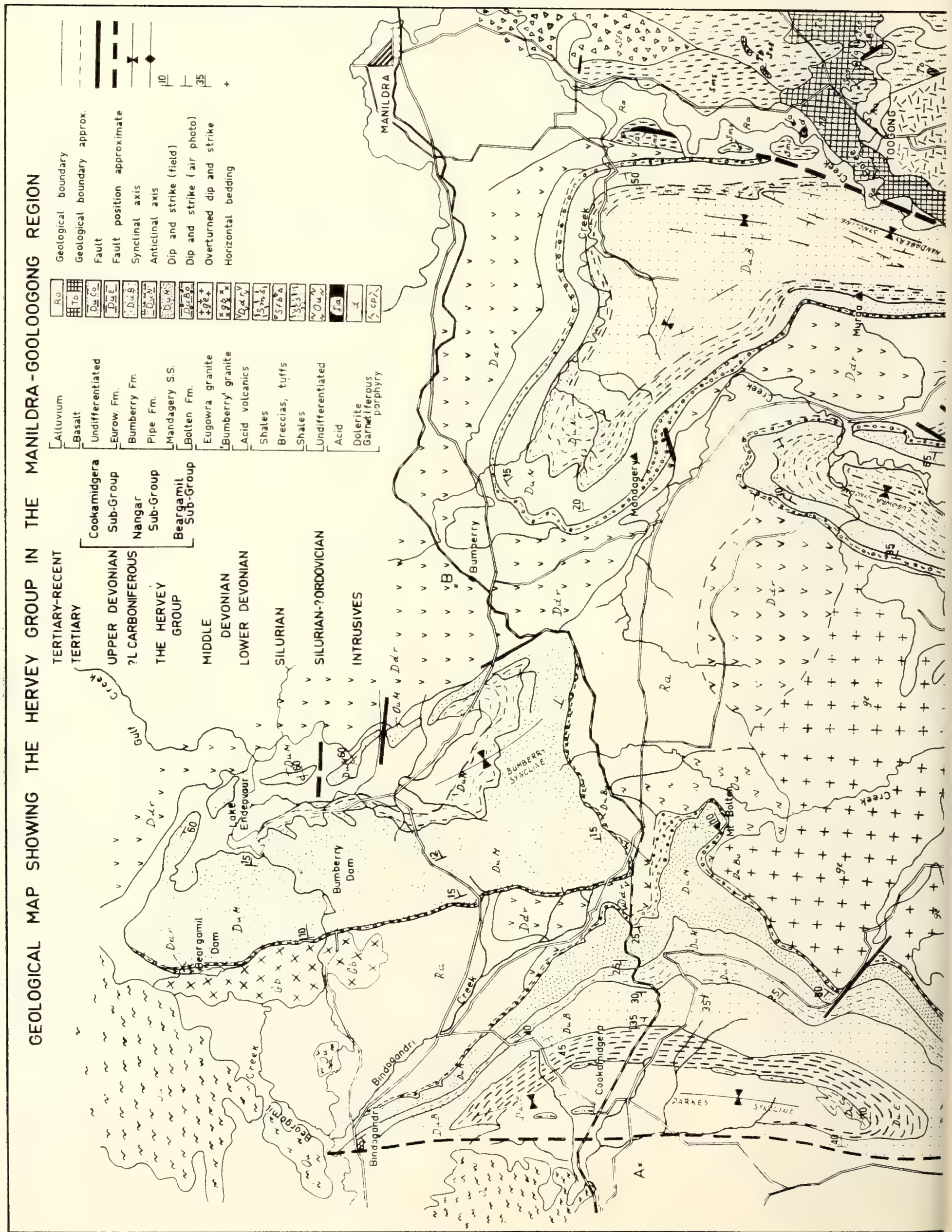
The type section was measured across the western limb of the syncline in the region of the headwaters of Burrill Creek about one mile to the west of the Kadina Trig. station. Here, there was more than 1,000 feet of fine-grained red beds with 250 feet of these beds near the base consisting of many medium to fine-grained sandstone members.

The formation is probably a lot thicker but erosion has removed the softer red beds leaving a valley which is the only land in the Hervey Syncline that has been cleared for cultivation. Poorly preserved fish-plates occur in fine-grained red sandstones near the base of the formation. They closely resemble some of the types associated with the *Bothriolepis* fauna in the Caloma Sandstone.

The Manildra-Gooloogong Region

The Hervey Group in the Manildra-Gooloogong district outcrops from two miles west of Manildra westwards for twenty miles towards Parkes and southwards for thirty-two miles to Gooloogong on the Lachlan River. Detailed stratigraphy and structure are shown on the geological map (Fig. 8) and the section diagram (Fig. 9). The geological map has been prepared from air photos and ground traverses using county maps and air photo mosaics as a base at a scale of one inch to one mile.

The geological boundaries and rock units in the Toogong area east of the Upper Devonian outcrop shown on Fig. 8 are for the most part those mapped by Dr. N. C. Stevens in his paper on the geology of the Canowindra district (Stevens, 1950). Later Mr. D. B. Walker (personal



communication) subdivided the Silurian in the Toogong area into an upper and lower shale sequence separated by a middle volcanic sequence. The more recent subdivisions of Walker are included on the geological map (Fig. 8).

In general the Upper Devonian rocks form thickly-wooded strike ridges with peaks 300 to 1,500 feet above the older Palaeozoic rocks. Two granites, the Bumberry Granite in the north, and the Eugowra Granite in the south, also form rugged ranges of similar relief. Creeks and rivers feed into the Lachlan River which flows westwards into a large and deep alluvial valley to the west of Gooloogong.

The Upper Devonian outcrops in five simple structural areas, called the Parkes, Eugowra,

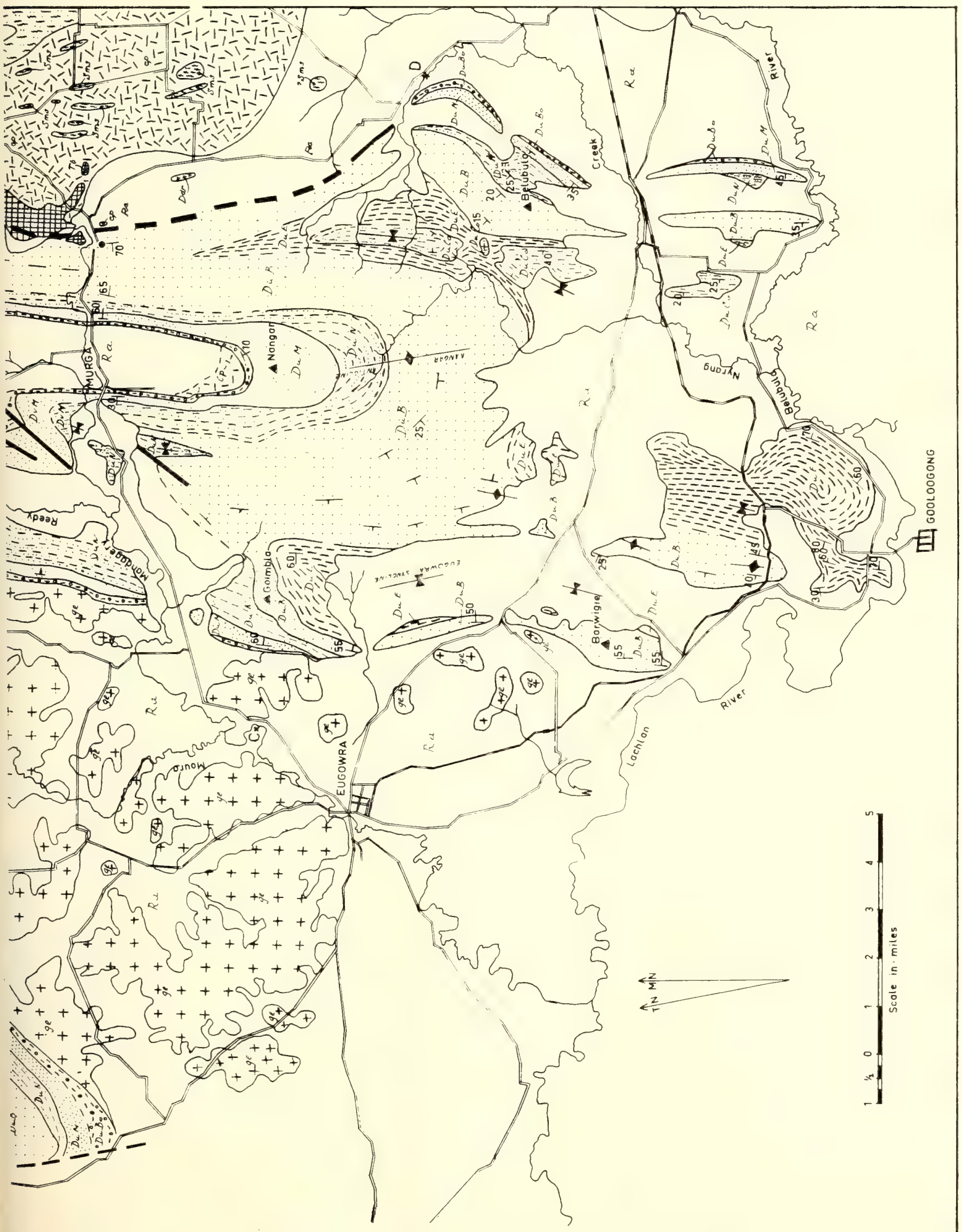


FIG. 8

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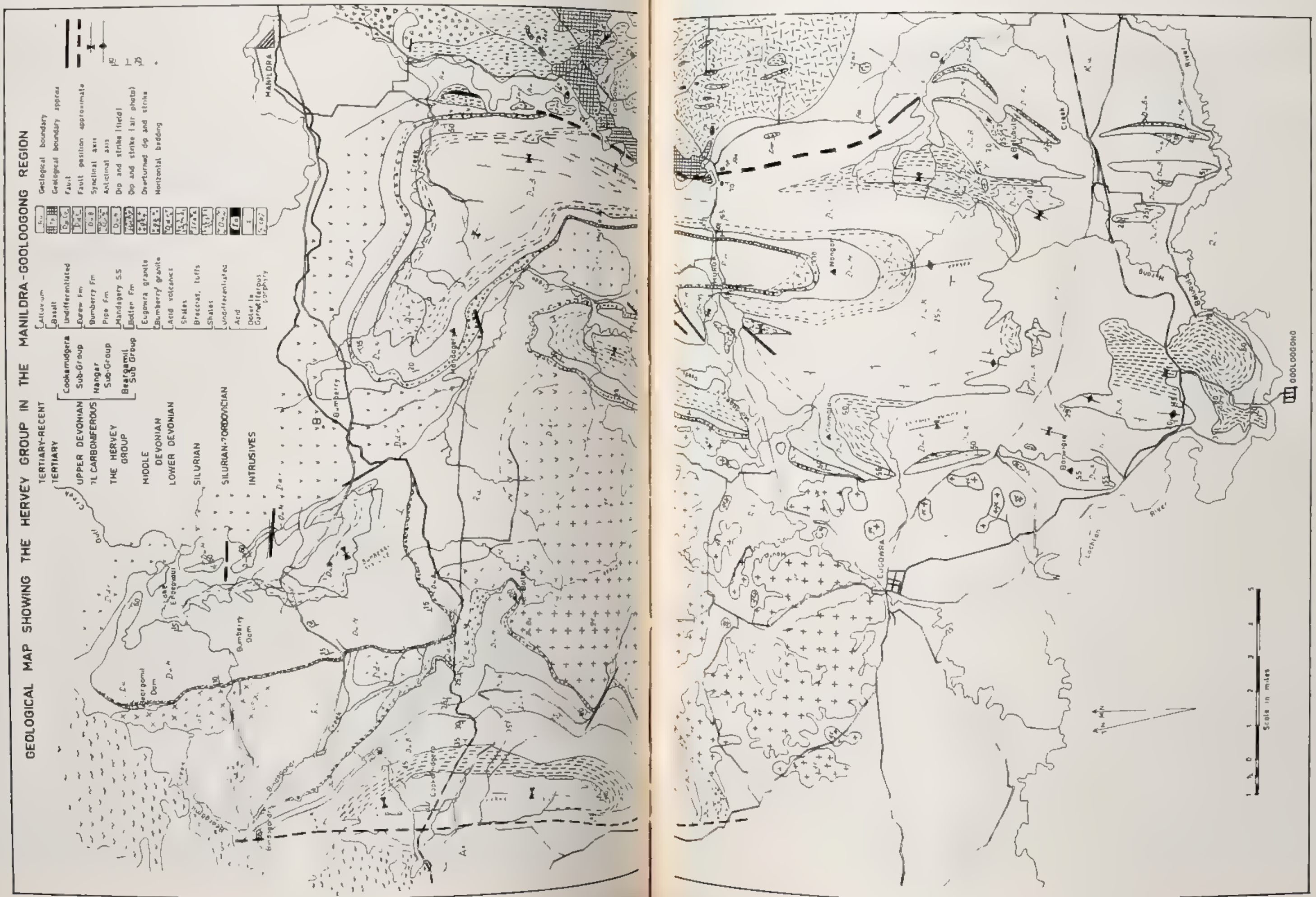


FIG. 8

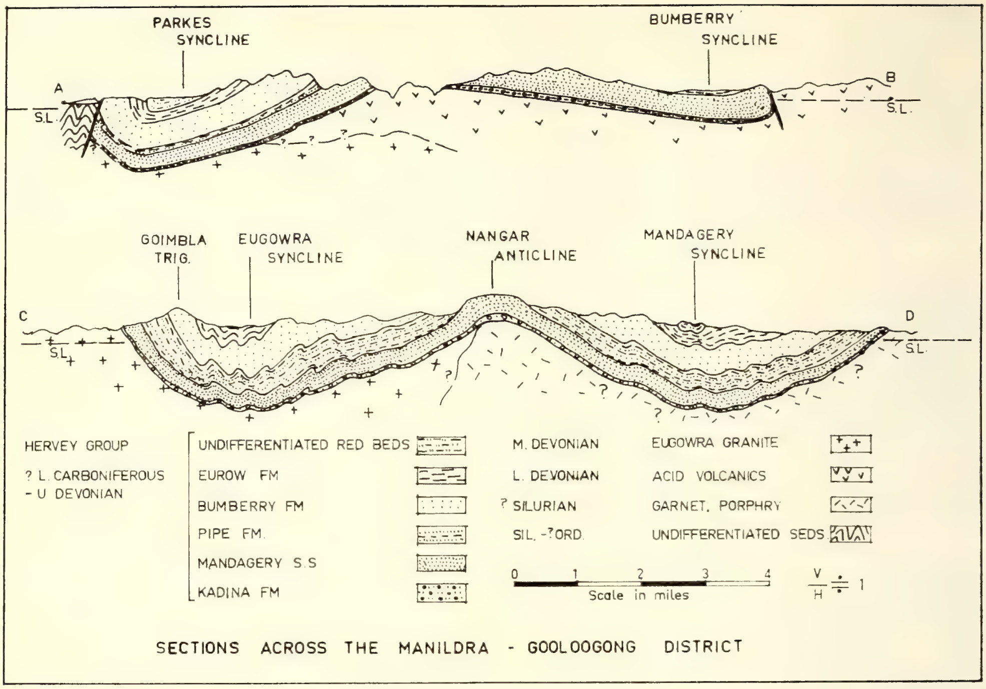


Fig. 9

Bumberry and Mandagery Synclines and the Nangar Anticline (Figs. 8, and 9).

The Parkes Syncline occurs eight miles east of Parkes and is a simple synclinal structure with a steeply-dipping western limb which has been faulted against older Palaeozoic sediments, and a shallowly-dipping eastern limb. The eastern limb is faulted against the Eugowra Granite with a lateral displacement of one mile in a south-easterly direction (Fig. 8).

The Bumberry Syncline is another very open structure adjoining the Parkes Syncline to the east and separated from it by older acid volcanics and granite over which the Upper Devonian sediments must have arched in a gentle anticlinal structure before erosion. This syncline has a shallow dipping western limb with low dips (ten to twenty degrees) but is steeply dipping, faulted and locally overturned against older acid volcanics on the eastern limb.

The Mandagery Syncline adjoins the south-eastern portion of the Bumberry Syncline and is separated from it by a distance of one mile, where erosion has removed a broad anticlinal arch. The Mandagery Syncline continues southwards from here a distance of twenty-six miles to the Lachlan River. The Nangar Anticline and the Eugowra Syncline adjoin the Mandagery Syncline to the west with continuity of outcrop. Faulting and minor folding with steep dips occur along the eastern side of the Mandagery Syncline immediately to the west of Toogong. Cliffs of sandstone form impressive strike ridges near Murga where the Nangar Anticline links the Mandagery and Eugowra Synclines. In the vicinity of the Nangar Trig. the Nangar Anticline has a rectangular shape with steeply dipping limbs and a very flat axial region.

Minor folding and faulting on the limbs of the southerly pitching Nangar Anticline are common to the north of Gooloogong where the uppermost red bed horizons of the Hervey Group are preserved.

The Upper Devonian sediments in the Manildra-Gooloogong region have been draped over older Palaeozoic basement rocks and subsequently folded into open structures except where there has been later movements in the basement causing localised steepening of dips and faulting. Between Parkes and Manildra, Upper Devonian rocks are folded with horizontal fold axes except for local shallowly-plunging fold noses. South of Eugowra, the Upper Devonian plunges steadily southwards bringing the younger sequences to the surface near Gooloogong.

Immediately to the west of the Parkes and Bumberry Synclines there is a large north-south

trending belt of folded older Palaeozoic sediments which include greywackes, quartz siltstones and shales and which extend several miles towards Parkes. No detailed mapping has been carried out in this area except for that of Hamilton (1961), who was unable to subdivide the succession. Overlying this succession unconformably is a thick sequence of acid lavas of probable early Devonian age. Intruding the older sediments and the acid volcanics are two granite masses, the Eugowra and Bumberry Granites.

The Hervey Group in the Manildra-Gooloogong region consists of the following formations :

TOP	6. Undifferentiated	Cookamidgera Sub-Group
	5. Eurow Formation	
	4. Bumberry Formation	Nangar Sub-Group
	3. Pipe Formation	
	2. Mandagery Sandstone	
BASE	1. Kadina Formation	Beargamil Sub-Group

The Kadina Formation

The Kadina Formation is the only representative of the basal red beds of the Beargamil Sub-Group in the Manildra-Gooloogong region. It consists of red beds most of which are red shales and siltstones, but fine-grained conglomerate and sandstone members are also common. At Mt. Bolten on the eastern limb of the Parkes Syncline the Kadina Formation consists of a total thickness of 350 feet of red siltstone and shale unconformably overlying older Palaeozoic green shales of probable Silurian age.

The Kadina Formation is nowhere of any great thickness in the Manildra-Gooloogong region and generally the thickness varies from 100 to 400 feet. The greatest thickness measured was in the vicinity of the Nangar Trig. where the sequence was 650 feet thick. The sediments are characteristically very red in colour, with poorly sorted arkosic and lithic sandstone lenses interbedded with red siltstone.

The Kadina Formation immediately to the west of Beargamil Dam forms the type section for the Beargamil Sub-Group (mentioned previously) where thin lenses (one to two feet thick) of red conglomerates with acid lava and granitic pebbles are common. Sedimentary structures include ripple marks, current bedding, tracks and burrows of worms, and mudcracks. The Kadina Formation frequently overlies granite and good exposures are available showing the relationships of the basal beds to the granite basement. In one exposure in the eastern limb of the Parkes Syncline, basal red sandstones of the Kadina Formation thin onto boulders of granite basement. In many other exposures, basal red beds lie on the acid volcanics of probable Lower Devonian age with a marked unconformity.

The Mandagery Sandstone

The Mandagery Sandstone conformably overlies the red beds of the Kadina Formation and underlies red siltstones of the Pipe Formation. It is defined as the first white sandstone formation above the Kadina Formation and forms the basal formation of the Nangar Sub-Group, throughout the eastern outcrop area of the Hervey Group.

The Mandagery Sandstone consists of fine to medium-grained white sandstones interbedded with thin red and green siltstone and shale members. The top of the formation is defined as the last white sandstone member before a thick sequence of fine-grained red beds which constitute the Pipe Formation. The type section was measured along the main western railway line to Parkes near Mandagery Railway station (Fig. 8), where the following sequence occurs :

TOP	Interbedded white sandstones, red siltstones and green shales	200′
	Massive white and buff sandstones ..	150′
	White sandstones with some shales ..	180′
	White siltstones and sandstones with many shale members	340′
	Massive white sandstone	150′
	White sandstones with red and green shales	160′
	Green and white siltstones with some white sandstones	320′
	Massive white sandstone and green siltstones	60′
	Green and red siltstones and shales with some white sandstones	240′
	Fine-grained white sandstones and siltstones	300′
BASE	Massive white and red sandstones ..	150′
	TOTAL THICKNESS	2,250′

This section is also given in columnal form on Fig. 10.

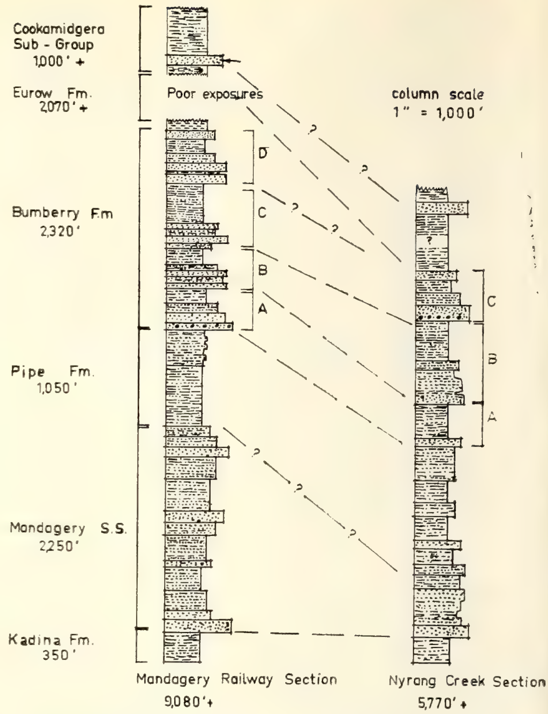
The Mandagery Sandstone varies considerably in thickness (Fig. 4), thinning gradually southwards, eastwards and northwards from Mandagery where it has a maximum recorded thickness. Sections measured in the north and south of the Parkes Syncline are 1,350 and 1,650 feet thick respectively, but there is a far more gradual thinning to the east with 1,800 feet exposed on the eastern limb of the Bumberry Syncline. Further east near Goimbla and Nangar Trigs., the Mandagery Sandstone is 1,300 and 1,100 feet thick respectively (Fig. 4).

Further to the south-east in the Nyrang Creek section (section J, Fig. 4), the Mandagery Sandstone is only 550 feet thick.

Poorly preserved fish plates are found in pebbly sandstone bands in the Bumberry Syncline and are probably related to the *Bothriolepis* fauna described from the Caloma Sandstone in the Hervey Syncline. A large slab of fine-grained red sandstone with several very well preserved species of *Bothriolepis* has been collected from the Mandagery Sandstone in a road cutting along the Canowindra-Gooloogong road about 16 miles from Gooloogong by Messrs. H. Fletcher and E. Rayner. Professor E. S. Hills (Fletcher, personal communication) has described the slab as containing two new species of *Bothriolepis* with many male and female forms of each. A nearly complete Bothriolepis was also collected by the writer from a nearby locality. Five miles due north of this locality a very large specimen of *Lepidodendron australe* was found in the Pipe Formation about 600 feet above the Mandagery Sandstone.

Sedimentary structures include current bedding, lenticular sandstones, ripple marks, scour and fill and slump structures. The spillway of Lake Endeavour Dam on the western flank of the Bumberry Syncline exposes over two hundred feet of fine- to medium-grained sandstones with most of the structures mentioned above. Current bedding is the dominant structure and the thickness of these units varies from several inches to three or four feet (Plate II, 1, 2). Current bedding tends to have basin shapes with the plunge directions of the basins in the direction of the palaeocurrent. Plate II, 2, shows a view of one of these basin-shaped current-bedded units with a plunge from the west. Although the bedding is sometimes uniform (Plate II, 3), lenticular sand masses are much more common (Plate II, 4). Curved and irregular beds are commonly deposited on flat surfaces. Arching of sedimentary layers to form convex-shaped structures is probably due to the formation of a hump or pseudo-hump due to deposition of a large mass of sediment on a depositional slope. Towards the top of the spillway very well formed slump structures are preserved in beds one to three feet thick. All these slumps plunge towards the west indicating a depositional slope dipping in that direction (Plate III, 2, 3).

The slumps are peculiar for they are rarely fractured or form convolute bedding, instead they are symmetrically elongated structures. Masses of sand lying on the depositional slope must have moved slowly and deformed



STRATIGRAPHIC COLUMNS OF THE HERVEY GROUP FROM THE MANDAGERY RAILWAY AND NYRANG CREEK SECTIONS IN THE MANILDRA - GOOLOOGONG REGION

Fig. 10

plastically to form such unbroken elongated slump structures.

Exposures of ripple marks are common in siltstones and uncommon in sandstones.

The Pipe Formation

The Pipe Formation conformably overlies the Mandagery Sandstone and underlies the Bumberry Sandstone. It is a shale and siltstone formation which forms valleys between Mandagery Sandstone and Bumberry Formation ridges. The siltstones are dominantly red in colour but some green or buff shales are found, and thin white and red sandstones occur sporadically throughout the formation. To the north of Nyrang Creek near the Belubula Trig. (Fig. 8), the following sequence was measured :

Top	Red siltstone and shale	150′
	Red siltstone, fine-grained red sandstone	100′
	Red siltstone, shales, several thin fine-grained red sandstone lenses	450′
	Red siltstone, fine-grained red sandstone	280′
	Red siltstone	250′
Base	Red siltstone, fine-grained red and white sandstone	350′
	Total Thickness	1,580,

The Pipe Formation thickens slowly towards Goimbla Trig. (Fig. 4, section G), where it attains a maximum thickness of 2,000 feet. From here it thins westwards and is 1,050 feet thick at Mandagery (Fig. 10) and is only 600 feet thick in the northern section of the Parkes Syncline.

The only fossils recorded from the Pipe Formation are Lepidodendrid plant remains which were found near Belubula Trig. in fine-grained sandstones. Sedimentary structures include small-scale current bedding, ripple marks and mudcracks.

The Bumberry Formation

The Bumberry Formation conformably overlies the Nyrang Formation and underlies the red beds of the Cookamidgera Sub-Group. It is the Upper formation of the Nangar Sub-Group and consists of distinct cycles of white and red beds and hence cannot be positively correlated with the Caloma Sandstone in the Hervey Syncline. The Bumberry Formation has a type section in the Mandagery Railway section illustrated on Fig. 10, and is named after the village of Bumberry several miles to the east of this locality.

The following sequence occurs in the type section :

Top	Cycle D	
	Fine-grained white sandstone	150′
	Red siltstones and shales	140′
	White and red sandstones and siltstones	90′
	Massive white sandstone	120′
	Red siltstone	20′
	Massive white sandstones and pebbly sandstones	110′
	Cycle C	
	Red siltstones, red and green shales and fine-grained white and red sandstones	470′
	White sandstones	70′
	White sandstones with red and green shales	60′
	Massive white sandstone	80′
	Interbedded sandstone and shale ..	80′
	Cycle B	
	Erosional gap, mainly red siltstones ..	180′
	Sandstone, siltstone and shales.. ..	60′
	Massive white and buff sandstones ..	60′
	Fine-grained white sandstone with some shale	70′
	Massive white coarse-grained sandstone	80′
	Cycle A	
	Red siltstones	180′
	Interbedded sandstones and red siltstones	120′
	Massive white sandstones	100′
Base	Coarse white sandstones with pebbly layers at the base	80′
	Total Thickness	2,320′

The succession consists of four cycles which consist of the following units :

Top 1. Red siltstones, shales, some fine-grained sandstones.
2. Interbedded red siltstones and white sandstone.
Base 3. Massive white sandstones, generally with coarse-grained and pebbly sandstones at the base.

Frequently the fine-grained sandstones, siltstones and shales that comprise the top unit of this cycle form a very thick sequence. The fine-grained sediments of the Cookamidgera Sub-Group probably make an outstanding example of such a thick unit. The Bumberry Formation in the Nyrang Creek section consists of only three cycles, the fourth if present, being so thick that it must be considered as part of the Cookamidgera Sub-Group.

Lepidodendrid and fish-plate remains are found as poorly preserved imprints on white sandstones. Well preserved current bedding occurs in the massive white sandstones at the base of each cycle and measurements in the Mandagery section show a consistent palaeocurrent direction from the west throughout the formation.

The Eurow Formation

The Eurow Formation is a thick red siltstone and shale sequence conformably overlying the Bumberry Formation. The type section was measured in the Bumberry Syncline, the centre of which is occupied by the fine-grained red beds of the Eurow Formation and which forms the headwaters of Eurow Creek. Exposures of the Eurow Formation are always poor because of its non-resistant nature. An estimate of 2,070 feet of thickness of sediment in the Bumberry Syncline was made using aerial photos and average dip and width of surface exposure.

White sandstones form a thin sandstone member within the Eurow Formation in the Parkes Syncline. A similar sandstone and siltstone sequence overlies the Eurow Formation in the Nyrang Creek area, but these beds could only be mapped as undifferentiated upper Cookamidgera Sub-Group (Fig. 8). The Eurow Formation is the only named formation in the Cookamidgera Sub-Group in the Manildra-Gooloogong region and is poorly exposed except where the Nangar Anticline pitches to the south near Gooloogong where there is probably more than 2,000 feet of red beds exposed which could not be subdivided.

Lepidodendrid plant remains are found in flat-dipping Eurow Formation shales south of Goimbla Trig. in the Eugowra Syncline. They

are preserved as impressions in closely-fractured red siltstones alongside with numerous worm burrows. Mudcracks, worm tracks and burrows, ripple marks and small-scale current bedding are all common sedimentary structures.

The Gooloogong-Grenfell Region

The Hervey Group in the Gooloogong-Grenfell region extends southwards from the Lachlan River near Gooloogong about twenty to twenty-five miles towards the main western highway from Cowra to Grenfell (Fig. 11). The Upper Devonian sediments in this area outcrop in an east-west belt of anticlines and synclines which is an average of twenty miles wide. It is one of the largest single areas of outcrop of Upper Devonian sediments in New South Wales covering an area of approximately four hundred square miles.

Once again, the Upper Devonian rocks form rugged ranges with strike ridges rising 1,500 to 2,000 feet above the alluvial plain of the Lachlan River. Detailed stratigraphy and structure are shown on the geological map (Fig. 11) and the section diagram (Fig. 12).

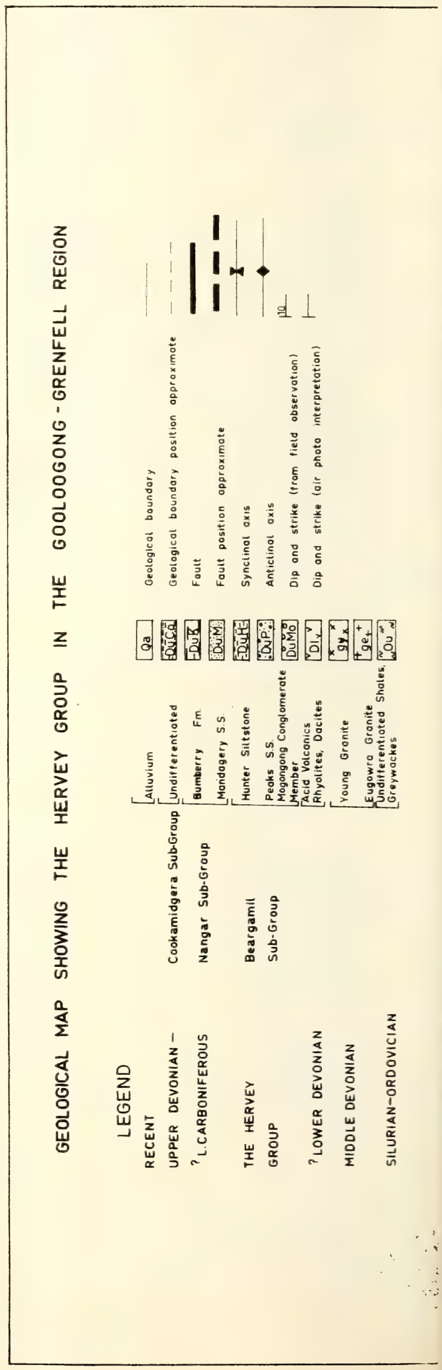
The sediments of the Hervey Group outcrop in four main synclines and three anticlines. From the west these structures include the Red Cliff Syncline, Gooloogong Anticline, Sugarloaf Syncline, Kangarooby Anticline, Conimbla Syncline, Broula Anticline and the northern extension of the Koorawatha Syncline.

Between Manildra and Grenfell (Fig. 4) the Hervey Group outcrops in a folded synclinal depression which pitches to the south to the north of Gooloogong, and to the north to the south of Gooloogong forming a deep basin of Upper Devonian sediments in the Gooloogong region.

Stevens (1950) mapped the far eastern boundary of the Upper Devonian sediments from west of Canowindra southwards along the Lachlan River towards Cowra. He noted that these sediments all dipped to the west and consisted of interbedded grits, quartzites and shales. Apart from this, no detailed investigation has been made of the Upper Devonian sediments in the Gooloogong-Grenfell area.

David and Browne (1950, p. 157) mention a belt of quartz-rich sediments passing through Grenfell towards Parkes and Peak Hill of possible Ordovician age. This group of sediments is shown as undifferentiated sediments of possible Ordovician and Silurian age on the geological map (Fig. 11). They are quite highly folded and schistose in many places in the area to the north and south of Grenfell, and are intruded by the Eugowra granite to the west of Grenfell.

These sediments are characterised by sedimentary structures such as flow casts, slumps, and graded bedding suggesting fairly rapid



deposition by turbidity currents and are probably related to similar sediments now outcropping at Mandagery and south of Peak Hill. Overlying this group with a probable unconformity is a thick sequence of acid and intermediate volcanics and associated tuffaceous sediments and shales. These are correlated with similar volcanics from the Cargo-Toogong area (Fig. 8) on lithological grounds and are of possible late Silurian to early Devonian age.

The Hervey Group unconformably overlies these volcanics over a large area. They

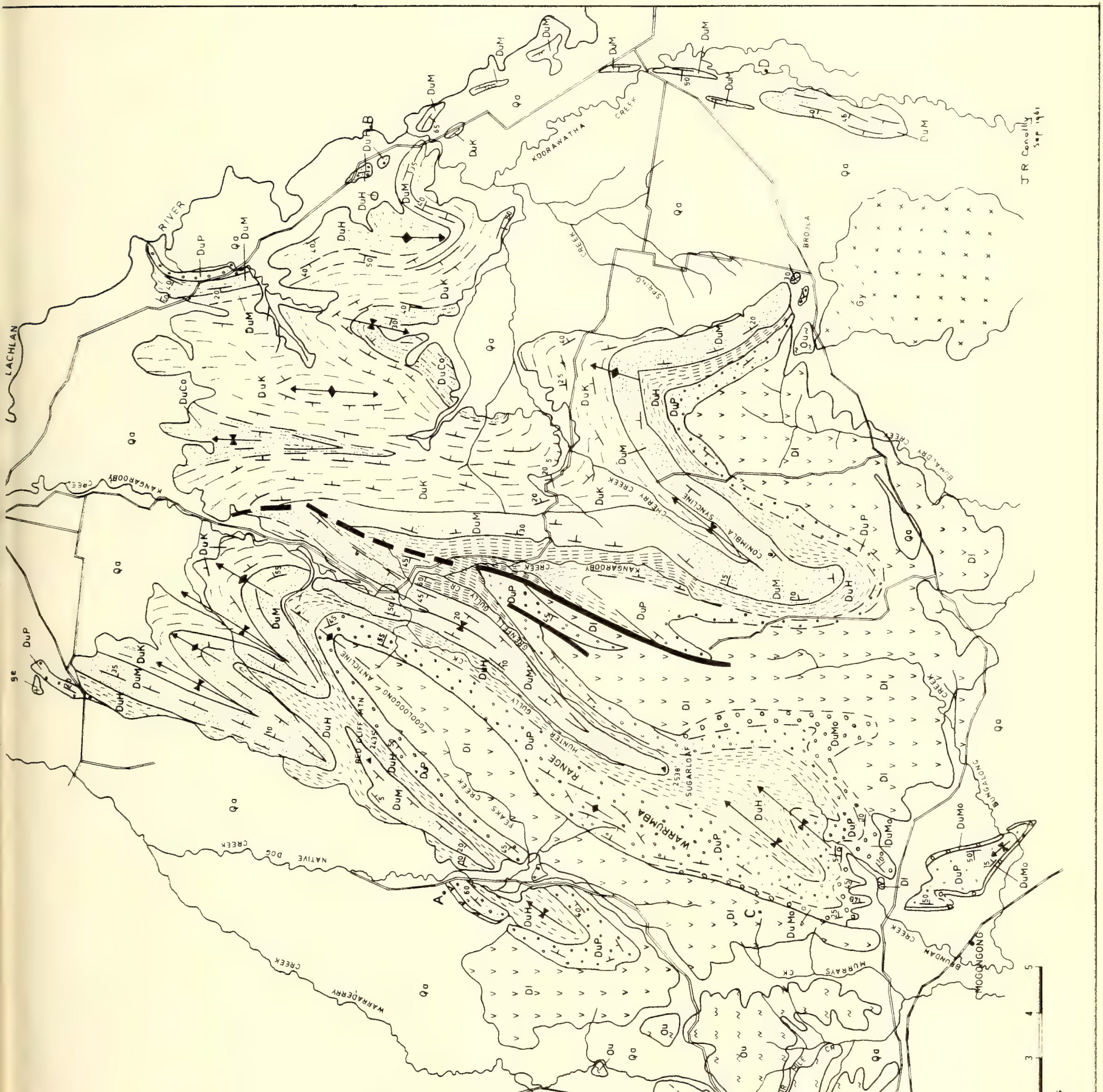


FIG. 11

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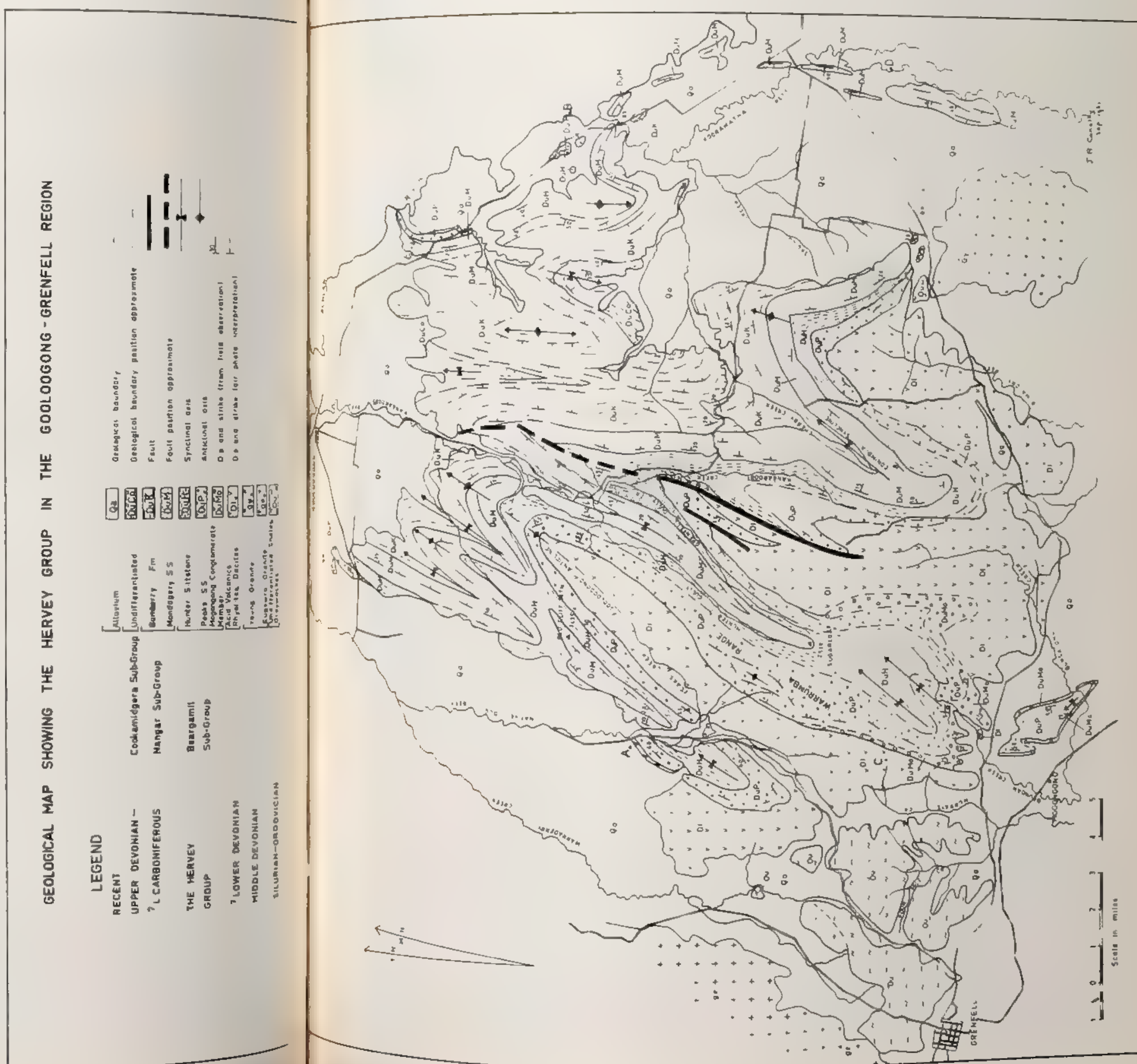


Fig. 11

deposition by turbidity currents and are probably related to similar sediments now outcropping at Mandagery and south of Peak Hill. Overlying this group with a probable unconformity is a thick sequence of acid and intermediate volcanics and associated tuffaceous sediments and shales. These are correlated with similar volcanics from the Cargo-Toogong area (Fig. 8) on lithological grounds and are of possible late Silurian to early Devonian age.

The Hervey Group unconformably overlies these volcanics over a large area. They

normally consist of quartz, felspar porphyries with a devitrified ground mass. Most are rhyolites or dacites but some intermediate and basaltic lavas occur in the axial region of the Gooloogong Anticline.

The Eugowra Granite outcrops northward across the Lachlan River to Eugowra. Since it intrudes the Ordovician and Silurian sediments and the volcanics mentioned above and is unconformably overlain by Upper Devonian sediments, a Middle Devonian age is postulated for this batholith (Plate III, 1).

The stratigraphy of the Hervey Group in the Gooloogong-Grenfell area is shown on Fig. 4. Six stratigraphic columns (columns K to P inclusive on Fig. 4) measured from ground traverses and air photos show variation in thickness for the formations of the Hervey Group.

The Peaks Sandstone, Mogongong Conglomerate Member and the Hunter Siltstone are all red bed formations belonging to the basal Beargamil Sub-Group which is considerably thicker in this area than in others. The rhythmic beds of the Nangar Sub-Group are represented by the Mandagery Sandstone and the Bumberry Formation which continue southwards from the Manildra district. The upper red beds of the Cookamidgera Sub-Group have not been subdivided in this area, although they do outcrop in two areas just to the south of Gooloogong (Fig. 11).

Although there is a far greater thickness of the Beargamil Sub-Group preserved with a thick basal conglomerate member developed in one area (the Mogongong Conglomerate Member) the stratigraphy of the Hervey Group is very similar to that of the Manildra-Gooloogong area, and can be summarised as follows :

5. Cookamidgera Sub-Group	
4. Bumberry Formation	Nangar Sub-Group
3. Mandagery Sandstone	
2. Hunter Siltstone	Beargamil Sub-Group
1. Peaks Sandstone	

The Peaks Sandstone

The Peaks Sandstone is the basal formation of the Beargamil Sub-Group in the Gooloogong-Grenfell region. It consists of red sandstones and grits interbedded with red siltstones and shales. There are numerous pebbly bands amongst the sandstones and the formation has a thick conglomerate member, the Mogongong Conglomerate Member, developed in the southern part of the Sugarloaf Syncline (Fig. 11).

The Peaks Sandstone unconformably overlies acid and intermediate volcanics in the type area at Peaks Creek in the eastern limb of the southern nose of the Red Cliff Syncline where the following sequence was measured :

Top	White and red coarse and medium-grained sandstones and red siltstone ..	150′
	Red siltstone	30′
	Red coarse-grained sandstones and red siltstone and red shale	190′
Base	Red siltstone and red shale	50′
	Total Thickness	420′

The top of the Peaks Sandstone is defined as the last coarse sandstone member (five to ten feet thick) underlying the thick sequence of red siltstones of the Hunter Siltstone.

The sandstone beds of the Peaks Sandstone are normally five to ten feet thick and pebbly layers are abundant. Whiter sandstones appear more frequently towards the top of the formation whereas the basal sandstones are mainly red in colour. The Peaks Sandstone everywhere rests on probable Lower Devonian acid or intermediate volcanics and their associated sediments, except four miles south-west of Gooloogong where they rest on the Eugowra Granite (Plate III, 1). In this locality the Peaks Sandstone consists of 350 feet of red grits, conglomerates and red and white coarse-grained sandstones. The Peaks Sandstone has a maximum recorded thickness of 1,500 feet in the Gooloogong Anticline. From this locality it thins rapidly to the east where only one or two hundred feet of sediment form the basal beds.

Thick current-bedded units occur in the massive red and white sandstones and measurements made in the western area of outcrop indicate a palaeocurrent from the west.

The *Mogongong Conglomerate Member* is a massive conglomerate member developed at the base of the Peaks Sandstone near Mogongong (Fig. 11). In the type section just north of the Cowra-Grenfell highway and three miles north of Mogongong the following sequence occurs :

	Coarse pebbly sandstones, thin conglomerate beds and red siltstone ..	200′
Base	Massive red conglomerate	120′
	Total Thickness	320′

The Mogongong Conglomerate Member thins out gradually five miles to the north and is thinning slowly to the south but does not outcrop further south than Bungalong Creek because of the plunge of the Upper Devonian rocks in this area. The Mogongong Conglomerate Member generally consists of a thick massive conglomerate member which is up to 150 feet thick with poor and indistinct bedding, overlain by interbedded conglomerates and sandstones which are well bedded. The pebbles vary in

size from one-half an inch to three inches in in diameter and consist mainly of fine-grained orthoquartzitic sandstones and siltstones, chert, vein quartz and acid volcanics.

Generally, the percentage of pebbles to sandy matrix is high and the characteristic basal conglomerate consists of 50 to 80 percent pebbles and the remainder of sandy matrix. However, the percentage of pebbles decreases with distance from the basal layers, and thin pebbly sandstones are the dominant coarse lithology in the topmost beds.

The Hunter Siltstone

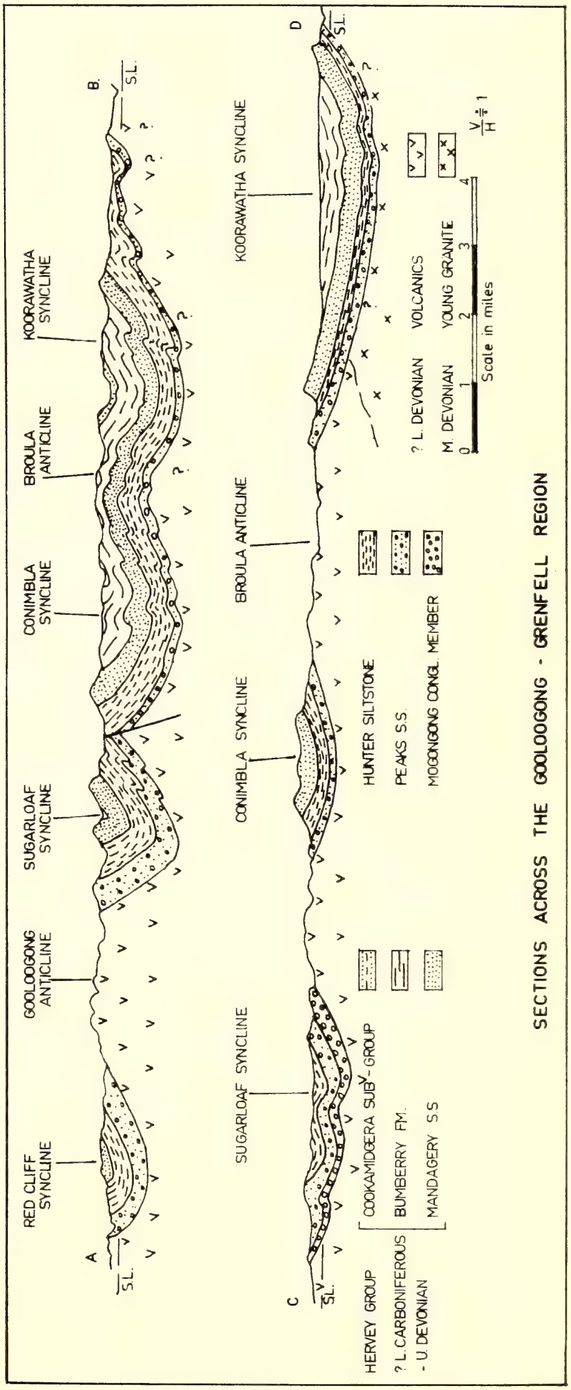
The Hunter Siltstone is a thick sequence of red siltstones and shales and a lesser proportion of fine-grained red sandstones conformably overlying the Peaks Sandstone and underlying the Mandagery Sandstone. It forms prominent valleys between the strike ridges of the Mandagery and Peaks Sandstones. The type section was measured on the eastern limb of the Gooloogong Anticline along the Hunter Gully Creek where a thickness of one thousand feet of red siltstone with occasional fine-grained red sandstone and shale members is calculated from width of outcrop and average dip. Unfortunately, the fine-grained sediments of the Hunter Siltstone do not form continuous outcrops and hence it is impossible to find a completely preserved section.

The Hunter Siltstone is a persistent formation and has estimated thicknesses that vary from 500 to 1,600 feet (Fig. 4). The maximum estimated thickness of 1,600 feet occurs on the eastern side of the region near the Lachlan River (column K, Fig. 4). Sedimentary structures include worm tracks and trails, mudcracks, ripple marks and small-scale current bedding in beds half an inch to one foot thick.

The Mandagery Sandstone

The Mandagery Sandstone conformably overies the Hunter Siltstone of the Beargamil Sub-Group in a similar fashion to the way it overlies the fine-grained red sediments of the Kadina Formation in the Manildra-Gooloogong region. The formation can be traced along the strike along the eastern side of the Manildra region across the Lachlan River down the eastern side of the Grenfell-Gooloogong region. Once again, the Mandagery Sandstone is the first thick white sandstone formation overlying the red beds of the Beargamil Sub-Group.

In the Grenfell-Gooloogong region the Mandagery Sandstone is five hundred feet thick on the north-eastern margin and maintains a thickness between 500 and 1,000 feet thick southwards towards Cowra (Fig. 4). It mainly consists of fine-grained sandstones with many white siltstones and some red siltstones. Five miles west of Cowra, where the Grenfell-Cowra highway crosses the most eastern strike ridge of



SECTIONS ACROSS THE GOOLOOGONG - GRENFELL REGION

Fig. 12

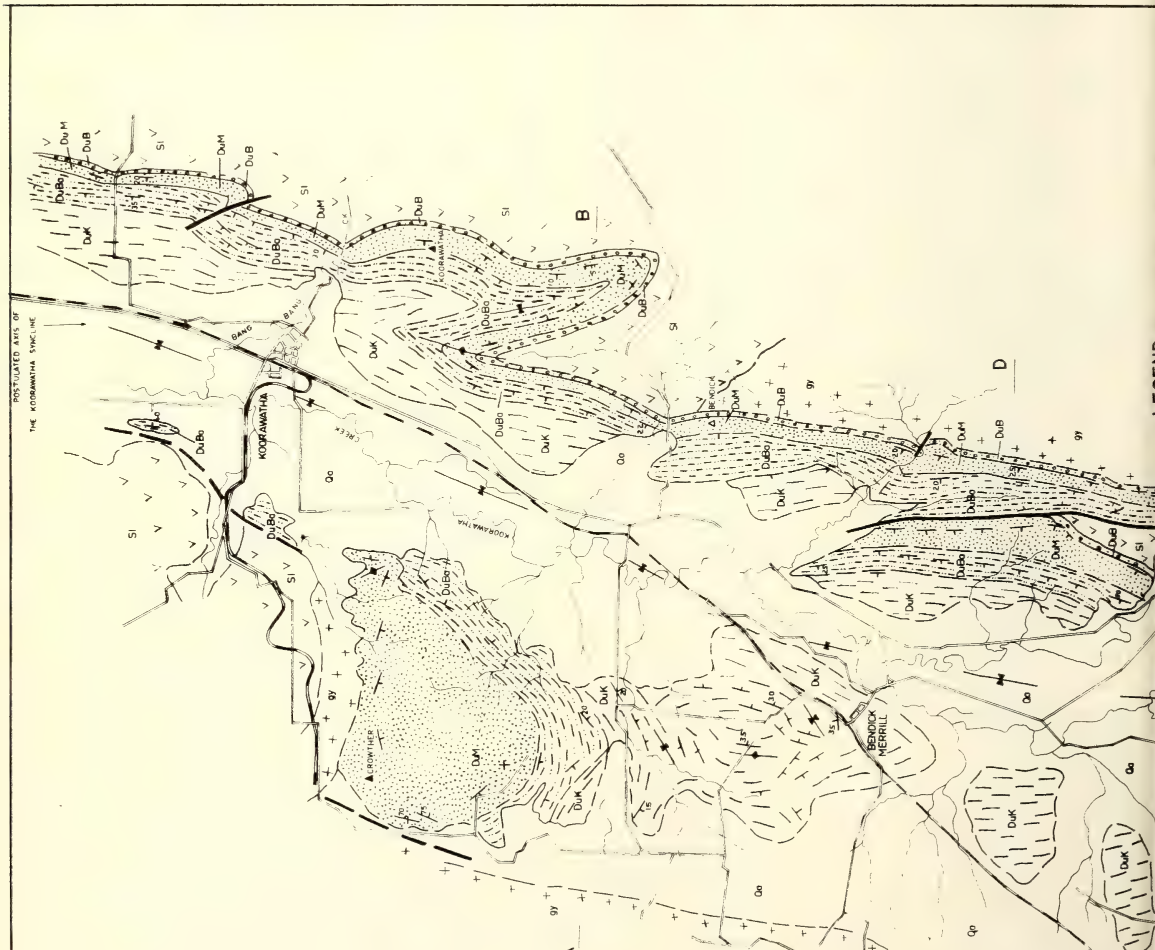
Mandagery Sandstone, fish plates, referable to the genus *Bothriolepis*, are found together with Lepidodendrid and Cordaitid plant remains. The Mandagery Sandstone thickens to 1,200 feet in the Gooloogong Anticline where it forms prominent ridge lines and steep dip slopes with screes.

Current bedding measurements in the Mandagery Sandstone indicate a palaeocurrent direction from the north-west. Ripple marks and small scale current bedding are common in smaller beds of fine sand or coarse silt grain size.

The Bumberry Formation

The Bumberry Formation continues southward from the Manildra district to the Gooloogong-Grenfell area. Once again this formation consists of a thick rhythmic succession of red and white beds. A section measured on the eastern limb of the Kangarooby Anticline along the back road from Gooloogong to Cowra consists of 3,000 feet of interbedded white sandstones and white siltstones with red sandstones and siltstones. However, there appears to be a far greater thickness of white sandstones than in the equivalent Bumberry Formation of the Manildra-Gooloogong region.

The Bumberry Formation is 3,200 feet thick to the north-east of the Kangarooby Anticline, but elsewhere erosion has removed most of its upper members (Fig. 4). White quartzite and sandstone ridges occur sporadically through a



sequence which consists mainly of fine-grained sandstones and coarse siltstones. Ripple marks and current bedding are the most frequent sedimentary structures. Current bedding measurements show that palaeocurrents came from the north-west and north.

Traces of fish plates and Lepidodendrid plant remains have been found in some medium to coarse-grained sandstones, but all were too poorly preserved for identification.

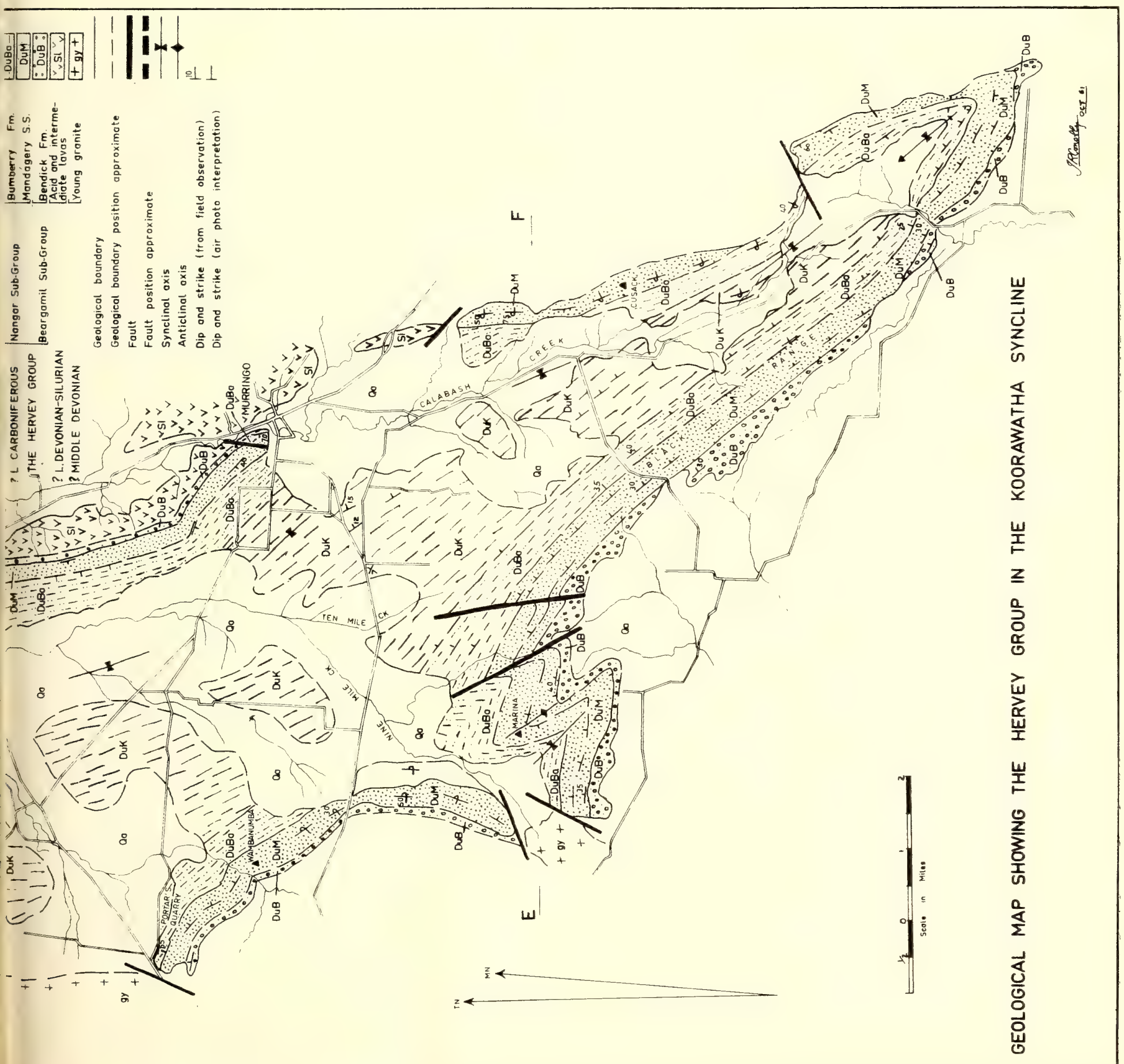
The Cookamidgera Sub-Group

The red beds of the Cookamidgera Sub-Group conformably overlie the Nangar Sub-Group and outcrop in only two localities, firstly within the northern extension of the Conimbla Syncline and secondly on the flank of the Broula Anticline (Fig. 11). In these localities 500 to 600 feet of red siltstones and shales outcrop in valleys. Low-lying strike ridges of fine-grained red and white sandstone members are the only beds that make good outcrops. Most of the succession consists of fine red sediments but there are several thin lenticular members of white sandstone.

Sedimentary structures include ripple marks and small-scale current bedding.

The Koorawatha Syncline

The Hervey Group in the Koorawatha Syncline extends from west of Cowra southwards to the east of Young (Fig. 4). The sediments



GEOLOGICAL MAP SHOWING THE HERVEY GROUP IN THE KOORAWATHA SYNCLINE

FIG. 13

Mandagery Sandstone, fish plates, referable to the genus *Bothriolepis*, are found together with Lepidodendrid and Cordaitid plant remains. The Mandagery Sandstone thickens to 1,200 feet in the Gooloogong Anticline where it forms prominent ridge lines and steep dip slopes with screes.

Current bedding measurements in the Mandagery Sandstone indicate a palaeocurrent direction from the north-west. Ripple marks and small scale current bedding are common in smaller beds of fine sand or coarse silt grain size.

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The Bumberry Formation is 3,200 feet thick to the north-east of the Kangarooby Anticline but elsewhere erosion has removed most of its upper members (Fig. 4). White quartzite and sandstone ridges occur sporadically through a

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GEOLOGICAL MAP SHOWING THE HERVEY GROUP IN THE KOORAWATHA SYNCLINE

FIG. 13

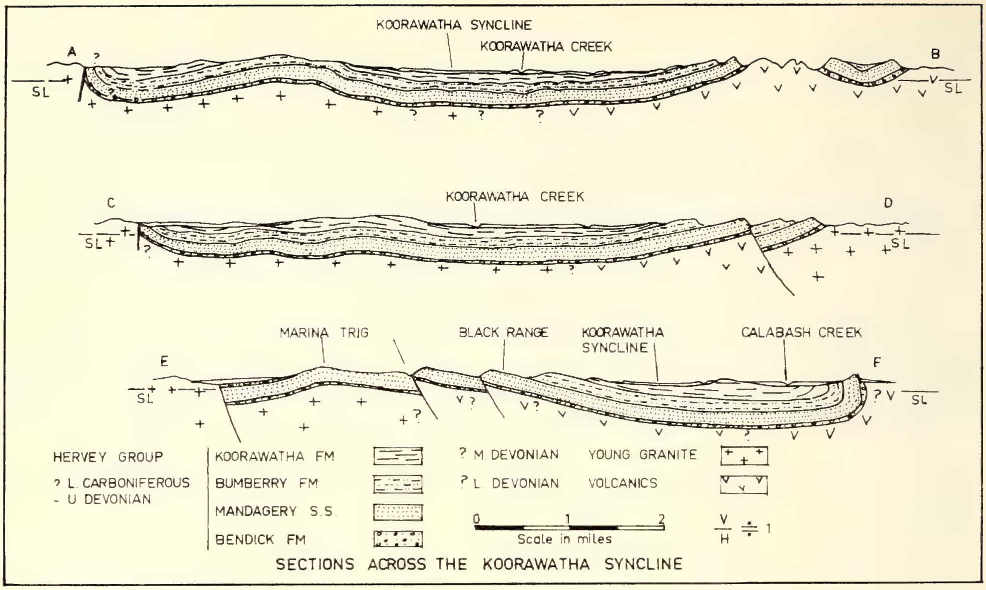


Fig. 14

in this area outcrop in a large long synclinal structure which originates to the north in the Gooloogong-Grenfell area near the headwaters of Koorawatha Creek and pitches very gently southwards, the axis following Koorawatha Creek and passing through the town of Koorawatha (Fig. 13). The total length of the structure from northern to southern nose is 50 miles and it has an average width of 8 miles. The area shown on Fig. 13 and described in this section is the southernmost 36 miles of the Koorawatha Syncline measured along the strike.

The Mandagery Sandstone mapped further north in the Manildra and the Gooloogong districts can be traced along the strike into the Koorawatha Syncline. It forms an excellent marker horizon, making a prominent ridge feature just above the basal red beds of the Beargamil Sub-Group. The topography is similar to other areas of Upper Devonian further north only the relief between the Hervey Group and older rocks is generally not nearly so great.

The central portion of the Koorawatha Syncline is marked by very few good outcrops and mainly consists of poorly-exposed red beds.

The geological map of the Koorawatha Syncline (Fig. 13) was prepared on an air photo base on a scale of 1 : 45,000 from ground traverses and air photo interpretation. Stratigraphic columns from the Koorawatha Syncline are shown on Fig. 4 and geological sections on Fig. 14.

The northern nose of the Koorawatha Syncline has already been discussed, in the previous section on the Gooloogong-Grenfell region. The southern and main portion of the syncline is a wide structure with minor folding and faulting along the limbs (Fig. 13, 14). Minor folds on the limb of the main structure occur three miles to the south-east of Koorawatha, four miles to the east of Bendick Murrell, five miles to the south-west of Murringo, and in the upper red beds in the synclinal axial region near Bendick Murrell. Many of these open structures are faulted, and to the south of Murringo, the eastern limb of the Koorawatha Syncline has been overturned and faulted against older acid and intermediate volcanics.

In the vicinity of the Marina Trig. minor anticlines and synclines occur on the south-western limb of the Koorawatha Syncline. Two of these minor structures are faulted with the eastern limb moving to the north. Faulting also brings the Young Granite against the Upper Devonian in this area with overturning of the western limb of the syncline near Wambanumba Trig.

North of Portar's Quarry, near Wambanumba Trig. on the western limb of the Koorawatha Syncline, there is a physiographically depressed area of Young Granite and alluvium and the lower beds of the Hervey Group do not outcrop.

It is possible that many of these lower beds have been faulted against the Young Granite in this area. Similar relationships may exist

further north near Koorawatha where faulting separates Hervey Group sediments from older lavas and granite.

Only two rock groups outcrop unconformably or faulted against the Hervey Group sediments of the Koorawatha Syncline. They are the Young Granite and a thick sequence of acid and intermediate lavas.

N. C. Stevens continued his mapping (Stevens, 1950, 1951) southwards, to the east of the Koorawatha Syncline, but this work has not been published and Stevens only prepared draft maps of the geology to the east of the Koorawatha Syncline. Since this time an unpublished geological map has been produced by Mr. D. Wynn of the New South Wales Geological Survey, showing the regional geology of the Young district. No other detailed geology has been carried out or published in this area.

The granite, called the Young Granite, that underlies and is faulted against the Hervey Group is probably a southern extension of the Eugowra Granite and may be of much the same age. However, the large group of acid and intermediate volcanics that underlie the Hervey Group and which have been intruded by the Young Granite are essentially more basic than the volcanics of the Manildra-Grenfell area. Their age is tentatively ascribed to the Lower Devonian or Upper Silurian.

Stratigraphy

The stratigraphy of the Hervey Group in the Koorawatha Syncline is illustrated in three columns (columns Q to S) on Fig. 14. The Beargamil Sub-Group is thin, represented only by the Bendick Formation. The Nangar Sub-Group is represented by the Mandagery Sandstone and the Bumberry Formation which continue southward from the Gooloogong area. Overlying the Bumberry Formation is a thick succession of red measures which has been called the Koorawatha Formation and tentatively placed in the Cookamidgera Sub-Group.

The Hervey Group reaches a maximum thickness of nearly 4,000 feet near Bendick Murrell, which is considerably less than the 9,000 feet preserved in the Manildra district. However, it is thought that quite a large thickness may be missing due to erosion.

The Bendick Formation

The Bendick Formation is the basal formation of the Hervey Group in the Koorawatha Syncline and the only representative of the basal red beds of the Beargamil Sub-Group. It mainly consists of red shales and siltstones, but fine-grained red sandstone members and poorly-sorted conglomerates occur in some areas. The type section was taken three miles south of the Bendick Trig. on the eastern limb of the Koorawatha Syncline (Fig. 13). Here the basal red beds unconformably overlie the Young Granite and the following section was measured:

Top	Red fine-grained sandstone and red siltstones with some white sandstone ..	60′
	Red siltstone, red conglomerate and coarse-grained sandstone	50′
Base	Red siltstones and red shales	70′
	Total Thickness	180′

Overlying the upper red beds of this formation is the basal coarse-grained white sandstone and pebbly sandstone of the Mandagery Sandstone. The Bendick Formation is generally quite thin and thicknesses between 100 and 300 feet are common throughout the area.

A thin bed of red conglomerate preserved to the north-east of Koorawatha contains many limestone fragments and is cemented by hematite. Red grits are common near the base of the formation but conglomerates similar to one described above are rare.

Traces of poorly preserved fish plates were found in red sandstones that underlie the massive white sandstones of the Mandagery Sandstone. No other fossils have been found in the Bendick Formation.

Sedimentary structures include ripple marks, current bedding, and worm burrows.

The Mandagery Sandstone

The Mandagery Sandstone has been mapped from the Gooloogong area southwards along the eastern limb of the Koorawatha Syncline. It forms the first white sandstone formation above the red beds of the Bendick Formation in the Koorawatha Syncline.

The Mandagery Sandstone is 400 to 500 feet thick north of Koorawatha and thickens gradually southwards till it is 800 feet thick near Bendick Murrell (Fig. 4). It thickens still more to the south and is 1,600 feet thick (column Q, Fig. 4) in a section across the Black Range in the southern nose of the syncline. The basal beds of the Mandagery Sandstone in the Koorawatha Syncline are alwasy very coarse grained with the development of pebbly sandstones and quartz-pebble conglomerates.

Measurements of current bedding in these coarse-grained sandstones indicate a palaeocurrent direction from the north-east near Koorawatha and from the north and east further south towards Bendick Murrell. Near Marina Trig. palaeocurrent directions swing slowly from

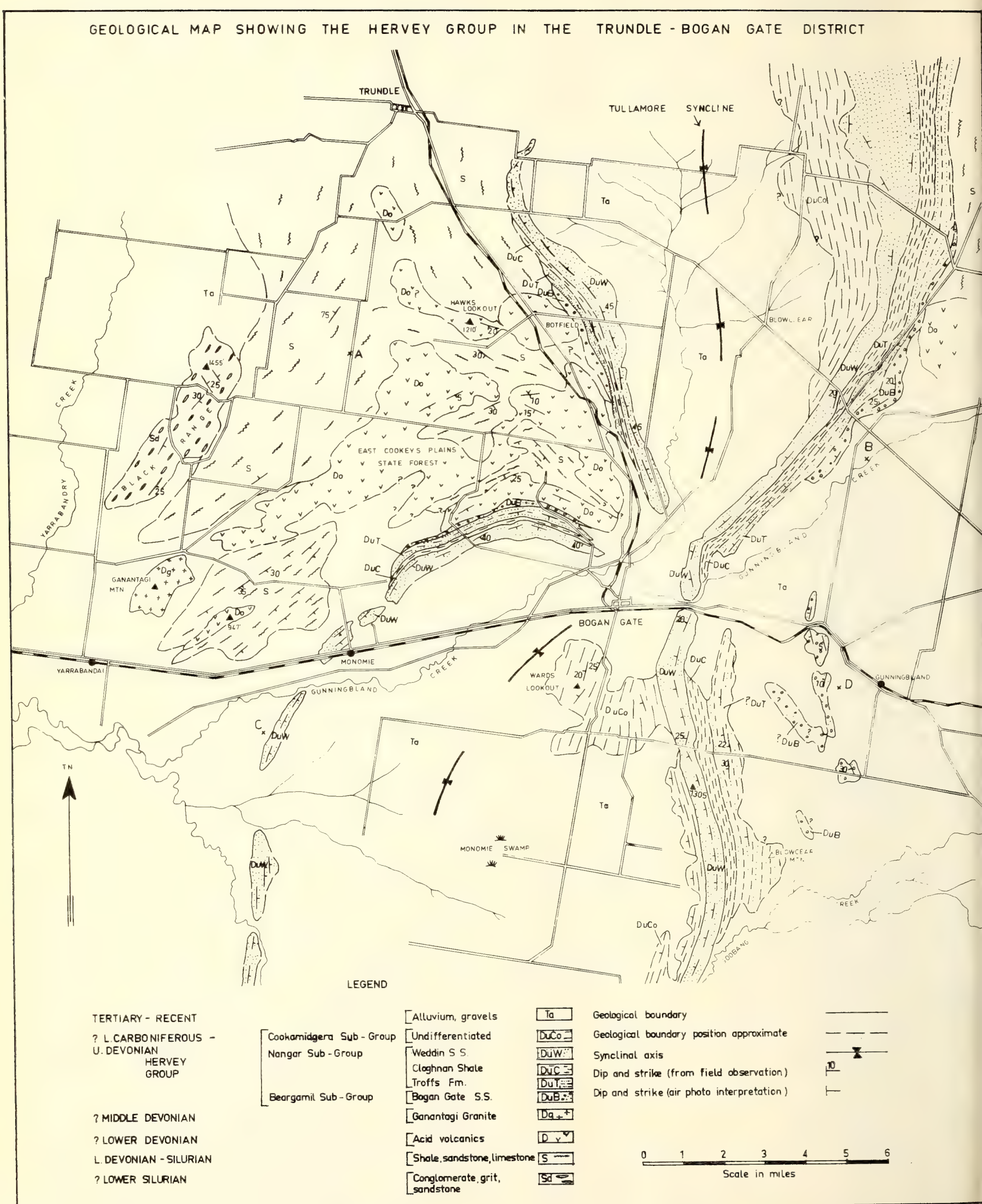

GEOLOGICAL MAP SHOWING THE HERVEY GROUP IN THE TRUNDLE - BOGAN GATE DISTRICT
TRUNDLE
TULLAMORE SYNCLINE
HAWKS LOOKOUT
BOTFIELD
BLACK RANGE
EAST COOKEYS PLAINS STATE FOREST
GANANTAGI MTN
BOGAN GATE
YARRABANDAI
MONOMIE
GUNNINGBLAND
WARDS LOOKOUT
MONOMIE SWAMP
YARRABANDRY CREEK
GUNNINGBLAND CREEK
TN
LEGEND
TERTIARY - RECENT
? L. CARBONIFEROUS - U. DEVONIAN HERVEY GROUP
Cookamidgera Sub - Group
Nangar Sub - Group
Beargamil Sub - Group
? MIDDLE DEVONIAN
? LOWER DEVONIAN
L. DEVONIAN - SILURIAN
? LOWER SILURIAN
Alluvium, gravels Ta
Undifferentiated DuCo
Weddin S S. DuW
Cloghnan Shale DuC
Troffs Fm. DuT
Bogan Gate S.S. DuB
Ganantagi Granite Dg
Acid volcanics Dv
Shale, sandstone, limestone S
Conglomerate, grit, sandstone Sd
Geological boundary
Geological boundary position approximate
Synclinal axis
Dip and strike (from field observation)
Dip and strike (air photo interpretation)
0 1 2 3 4 5 6
Scale in miles

FIG. 15

north-east towards the north-west in the southern parts of the Koorawatha Syncline.

The coarse sandstones and conglomerates at the base of the Mandagery Sandstone are normally 35 to 50 feet thick. Overlying these sediments there is a thick sequence of fine and medium-grained sandstones. South of the Marina Trig. along the western limb of the Koorawatha Syncline there are two ridges of coarse sandstone in the Mandagery Sandstone separated by a thick sequence of fine-grained white sandstones and white and red siltstones.

Stems of *Lepidodendron* have been found in the Mandagery Sandstone at Portar's Quarry near the main road to Young on the western limb of the Koorawatha Syncline. Poor traces of fish plates were also found along the strike ridge near Portar's Quarry.

The Bumberry Formation

The Bumberry Formation overlies the Mandagery Sandstone and consists of interbedded white sandstones, red siltstones, and shales. A section measured where Bang Bang Creek cuts through the eastern limb of the Koorawatha Syncline just to the east of Koorawatha, showed the following sequence :

Top	White sandstones and red siltstone ..	120′
	Red siltstone and shale	50′
	White sandstones and red siltstone ..	260′
	White sandstone	30′
Base	Red siltstones with some white sandstone members	100′
	Total Thickness	560′

The formation essentially consists of cycles of white sandstone that grade into red siltstones and shales, typical of the Nangar Sub-Group. The Bumberry Formation thickens to the south where it is approximately 1,400 feet thick (column Q, Fig. 4).

Sedimentary structures include current bedding, ripple marks, and mudcracks. Current bedding measurements in several localities indicated a palaeocurrent direction from the north and north-east. The Bumberry Formation is conformably overlain by the Koorawatha Formation.

The Koorawatha Formation

The base of this formation is defined as the first thick (300 ft.) red siltstone or shale member after the highest massive white sandstone member of the Bumberry Formation. The formation consists almost entirely of red beds and hence it is believed to represent the Cookamidgera Sub-Group in the Koorawatha Syncline.

Generally outcrops are poor, but good exposures occur in the vicinity of Bendick Murrell where medium-grained red sandstones of the Koorawatha Formation are folded into a series of open synclines and anticlines (Fig. 13). It is hard to find exposures of the Koorawatha Formation that would contribute to the compilation of a complete section, since the red beds are easily eroded and make poor outcrops. However, an estimate of the exposed thickness in the Koorawatha district is over 1,000 feet of red beds and this has been chosen as the type area.

No fossils have been found in this formation, but sedimentary structures such as ripple marks and small-scale current bedding are abundant.

The Tullamore-Weddin Range District

The sediments of the Hervey Group outcrop in a large synclinal structure called the Tullamore Syncline in the Tullamore-Bogan Gate district. South of Bogan Gate on the eastern limb of this syncline, strike ridges of Upper Devonian sandstone extend southwards and form the Jemalong and Corradgery Ranges. These ranges extend twelve miles south of the Lachlan River, beyond which there is no further outcrop except to the south-west where the Wheoga and Weddin Ranges outcrop (Fig. 3).

The outcrop distribution and stratigraphic columns measured of the Hervey Group from this area are illustrated on Fig. 5. The total length of outcrop of the sediments of the Hervey Group from the northern end of the Tullamore district, south to the Weddin Range is 110 miles. The area is generally very flat and the strike ridges of the Hervey Group rarely rise more than five hundred feet above older Palaeozoic rocks and more recent alluvium. The Weddin and Wheoga Ranges have the greatest relief, rising to heights of 1,000 to 1,500 feet above the surrounding plain.

Geological maps of the Bogan Gate-Trundle district (Fig. 15) and the Tullamore district (Fig. 17) were prepared from air photos and ground traverses. Separate maps of the Weddin and Wheoga Ranges were not prepared, for they are just simple strike ridges that dip to the south and west respectively.

Fig. 5 illustrates the outcrop of the Hervey Group from the Weddin Range to the Tullamore district. The Tullamore Syncline is the dominant structure of the area and only the Wheoga and Weddin Ranges outcrop away from it. These two ranges are strike ridges striking in the same direction as the eastern limb of the Tullamore Syncline but offset about twelve miles

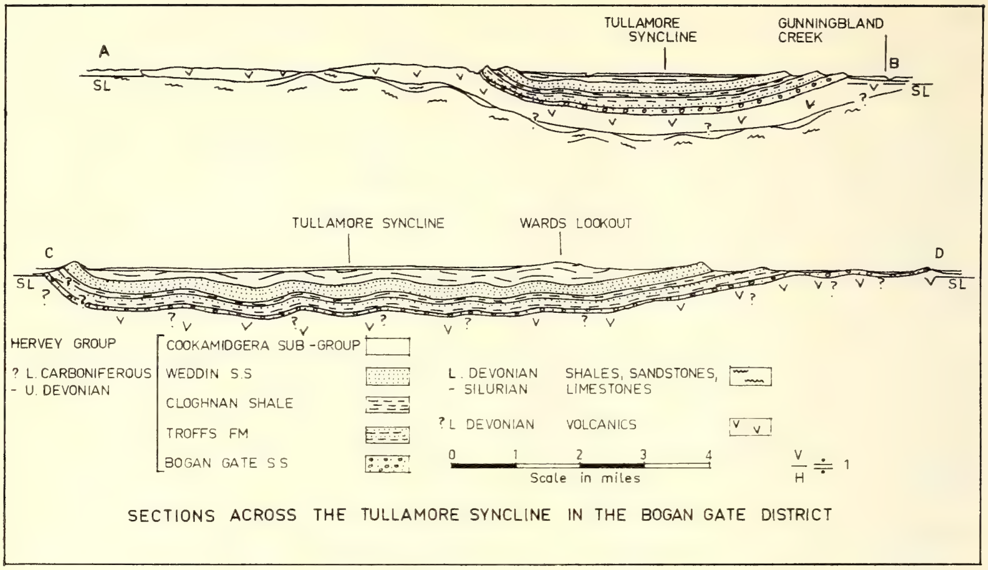


Fig. 16

to the east of the eastern limb of the Tullamore Syncline and probably represent the only outcropping remnants of another synclinal structure.

The Weddin Range represents the partly preserved northern side of a broad shallow basin which strikes east-west at its southern extremity, and north-south at its northern extremity. The range is 13 miles long, along the strike, and dip slopes of 5 to 20 degrees dip gradually to the south from high cliffs on the northern side, extending the outcrop of the range to an average distance of 5 miles in the direction of the dip.

The Wheoga Range is a strike ridge that is an erosion remnant of the northern extension of the Weddin Range. It dips to the west at angles of 30 to 40 degrees.

Geological maps (Figs. 15, 17) and section diagrams (Figs. 16, 18) show the structure of the Tullamore Syncline, which is an extremely large syncline with a total outcrop length of at least 80 miles, and an average width of 12 miles. Both limbs of the syncline pinch together near Bogan Gate where they are only one mile apart. North of Trundle, near the Troffs (Map 17), there is some minor folding on the western limb of the syncline producing a synclinal structure that pitches at a low angle to the north.

Regional Geology

Detailed investigations of the geology of the Tullamore-Weddin Range district include those by Raggatt (1937) and Andrews (1910). Raggatt (1937) made a regional geological reconnaissance of the Condobolin-Trundle district dubdividing the Palaeozoic succession in the following way:

Devonian		Quartz sandstone	2,000′
		Fine-grained sandstone, shale, limestone	700′
		Sandstone and conglomerate ..	2,000′
Silurian	Ootha Series	Claystone, sandstone, limestones, rhyolites, andesites.	
Silurian	Cobar Series	Slates, phyllites, some fossiliferous limestone, rhyolite.	

Because of poor outcrops and insufficient fossil evidence it is difficult to find the relationships between individual units of the Silurian and Devonian sequence. Apart from the distinctive Upper Devonian sediments and granitic outcrops it is possible to subdivide the sequence into a Devonian-Silurian sequence of sedimentary rocks which have been openly folded and are characterised by shallow or moderate dips. These rocks are, characteristically, sandstones, siltstones, shales, limestones and marls. Marine fossils of both Silurian and Devonian age have been described (Raggatt, 1937) from these sediments. These sediments are frequently overlain by a sequence of acid and intermediate volcanics.

On the geological maps (Figs. 15, 17) these two units, that is, the sedimentary sequence and

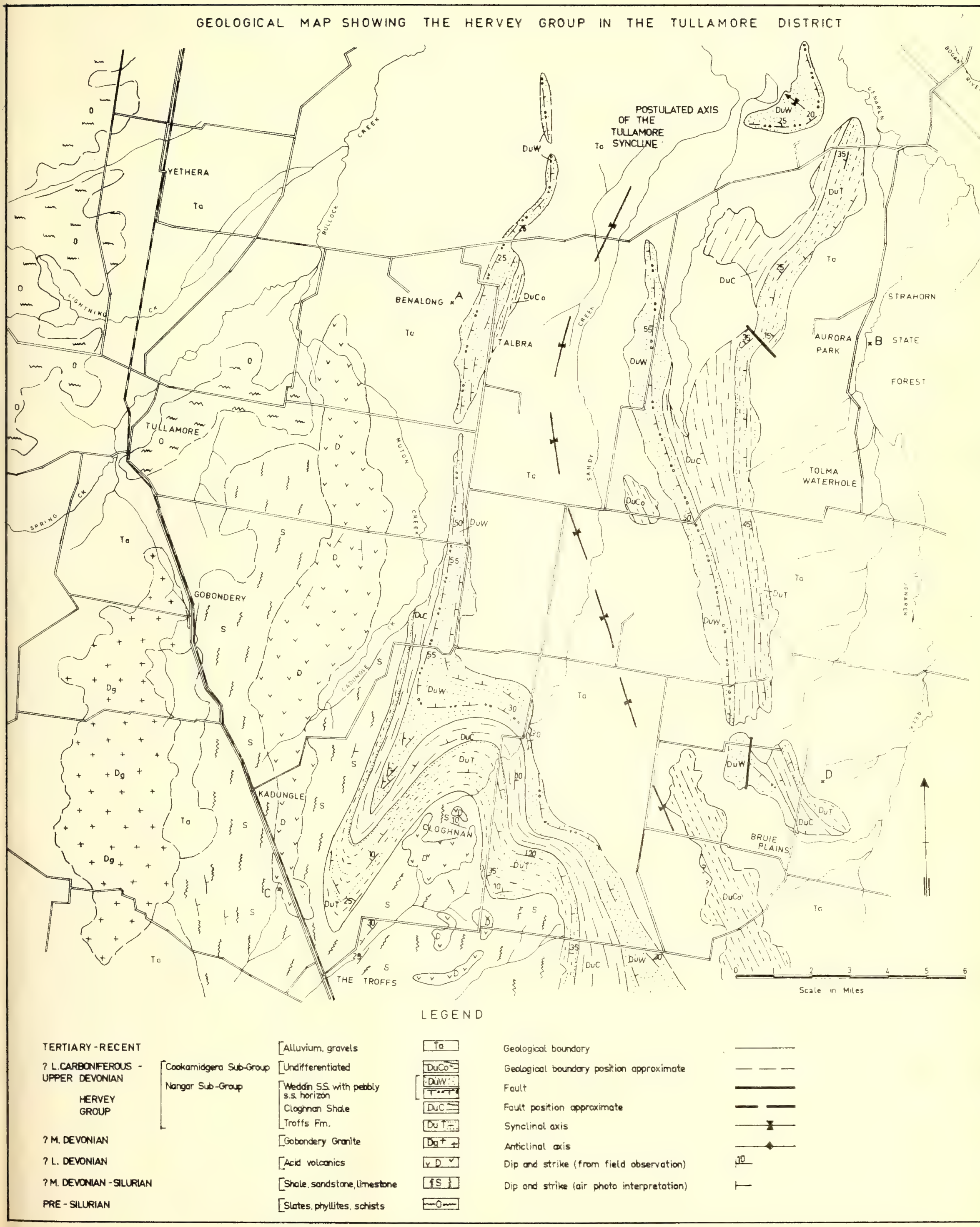

GEOLOGICAL MAP SHOWING THE HERVEY GROUP IN THE TULLAMORE DISTRICT
POSTULATED AXIS OF THE TULLAMORE SYNCLINE
YETHERA
BENALONG
TALBRA
TULLAMORE
GOBONDERY
KADUNGLE
CLOGHNAN
THE TROFFS
STRAHORN STATE FOREST
AURORA PARK
TOLMA WATERHOLE
BRUIE PLAINS
BULLOCK CREEK
LIGHTNING CK
SPRING CK
MUTON CREEK
CADUNGLE CK
SANDY CREEK
GENAREN
BOGAN RIVER
Scale in Miles
LEGEND
TERTIARY-RECENT
? L. CARBONIFEROUS - UPPER DEVONIAN
HERVEY GROUP
Cookamidgera Sub-Group
Nangar Sub-Group
? M. DEVONIAN
? L. DEVONIAN
? M. DEVONIAN - SILURIAN
PRE - SILURIAN
Alluvium, gravels
Undifferentiated
Weddin S.S. with pebbly s.s. horizon
Cloghnan Shale
Troffs Fm.
Gobondery Granite
Acid volcanics
Shale, sandstone, limestone
Slates, phyllites, schists
Ta
DuCo
DuW
DuC
DuT
Dg
D
S
O
Geological boundary
Geological boundary position approximate
Fault
Fault position approximate
Synclinal axis
Anticlinal axis
Dip and strike (from field observation)
Dip and strike (air photo interpretation)

Fig. 17

the volcanic sequence, have been differentiated. It is possible that part of the volcanic sequence is actually interbedded with the uppermost beds of the sedimentary sequence but more detailed mapping is required before this can be established. Both sequences probably belong to the " Ootha Series " as described by Raggatt (1937).

Underlying these rocks is a much older regionally metamorphosed sequence of quartz-mica schists, phyllites and slates, which is probably the equivalent of the Cobar Series as originally described by Raggatt (1937). Recent work in the Cobar district by Rayner (1962) has shown that a similar group of rocks outcrop in the Cobar district. Rayner has demonstrated that they are probably Ordovician in age and are separated from the overlying Devonian-Silurian sequence by an unconformity.

The deposition during the Silurian and Lower and Middle Devonian in the Tullamore-Bogan Gate district was essentially a shallow-water marine type with a high percentage of well sorted quartz-rich sandstones and calcarenites. This is in direct contrast to the somewhat deeper water sedimentation that was presumed to have taken place to the east of Forbes and Peak Hill.

The Silurian and early Devonian sequences in the Bogan Gate and Forbes district are intruded by granites, but the Upper Devonian is not intruded by granite. Hence the tentative age of the granite is considered to be Middle Devonian.

The Silurian and Devonian sequence underlying the Upper Devonian in the Tullamore Syncline is only very gently folded in large open folds similar to the folding style of the Upper Devonian. Yet, it appears that acid volcanism and granite intrusion took place after most of the Silurian-Devonian succession was deposited. In general, granites of this age are very rare in the Forbes-Bogan Gate district, and are normally only small stocks that have not metamorphosed or affected their intruded sediments to any great extent.

The Gobondery Granite that outcrops several miles to the west of The Troffs (Fig. 17), on the other hand, is a large granite massif which intruded the Silurian-Devonian sediments with significant contact metamorphism (Raggatt, 1937).

The surface on to which the Upper Devonian was deposited in the Tullamore-Bogan Gate-Forbes district is thought to have consisted of an undulating plain of sub-horizontal Silurian and Devonian sediments which were covered with acid volcanic flows in some areas.

Stratigraphy of the Hervey Group

The stratigraphy of the Hervey Group in the Tullamore-Weddin Range region is illustrated on Fig. 5. Eight stratigraphic columns (columns E to C, Fig. 5) show variations in stratigraphy.

The Upper Devonian rocks of the Hervey Group make a distinct unit, and can be subdivided as follows :

Top	Cookamidgera Sub-Group	Undifferentiated red beds
	Nangar Sub-Group	Weddin Sandstone Cloghnan Shale Troffs Formation
Base	Beargamil Sub-Group	Bogan Gate Sandstone.

All these formations outcrop in the Tullamore and Trundle-Bogan Gate districts (Figs 15, 17). Strike ridges of the massive sandstones of the Weddin Sandstone continue southwards to the Weddin Range where this formation has its type section.

The basal red beds of the Beargamil Sub-Group are represented by the Bogan Gate Sandstone which is well developed in the Bogan Gate district. North of Bogan Gate, basal red beds are rare or missing for the first time in the Hervey Group. Instead, marine sandstones and calcarenites of the Troffs Formation pass gradually into the basal fish plate-bearing sandstones of the Weddin Sandstone.

The Nangar Sub-Group can be divided into three formations called the Troffs Formation, the Cloughnan Shale and the Weddin Sandstone. The Troffs Formation consists of interbedded quartzose sandstones, siltstones and shales, and is best developed near The Troffs, north of Trundle (Fig. 17). The Cloghnan Shale consists mainly of siltstone and shale and overlies the Troffs Formation. It is also best developed to the north of Trundle in the vicinity of Cloghnan (Fig. 17). The Weddin Sandstone makes outcrops as high sandstone ridges from the Weddin Range to Tullamore in the north. It overlies the Cloghnan Shale in the Bogan Gate-Tullamore district but rests directly on the red beds of the Beargamil Sub-Group in the Weddin Range.

A red bed succession occurring above the Weddin Sandstone has been correlated with the Cookamidgera Sub-Group. Poor exposures make it impossible to subdivide this Sub-Group in the Tullamore-Weddin Range area.

The Bogan Gate Sandstone

The Bogan Gate Sandstone is the only named formation in the Beargamil Sub-Group in the Tullamore-Weddin Range area. In the type area at Bogan Gate, it consists of a succession

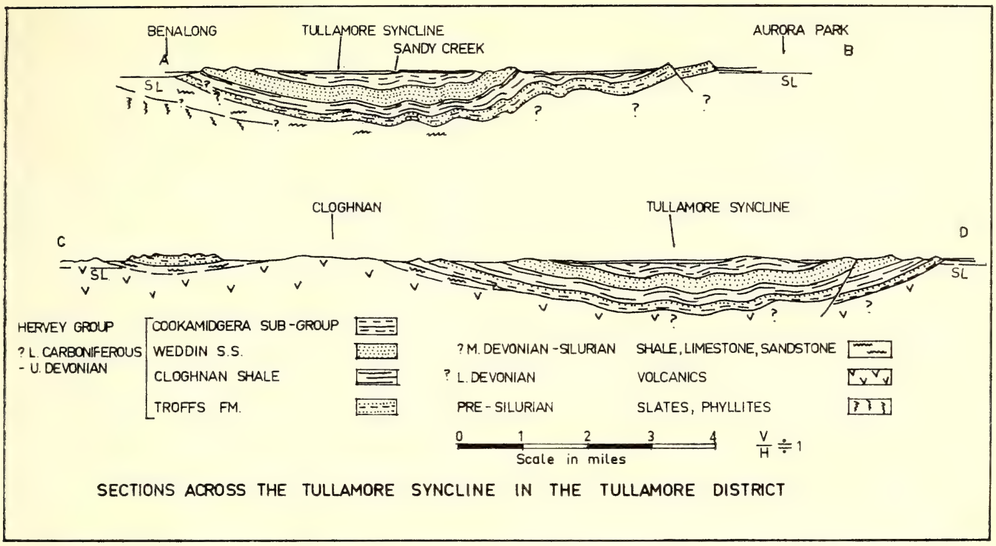


FIG. 18

of coarse-grained red sandstones, and interbedded red siltstones. To the south, in the Weddin Range, it mainly consists of fine-grained red sandstones and siltstones. To the north of Trundle, the Bogan Gate Sandstone is missing from the succession.

The type section was measured 12 miles north-east of Bogan Gate on the eastern limb of the Tullamore Syncline (column F, Fig. 5). In this locality the Bogan Gate Sandstone dips at angles of 20 to 30 degrees under the strike ridges of the Troffs Formation. The following succession was measured in the type section :

TOP	Red shales and siltstones	110′
	Coarse-grained red sandstone, red siltstone	300′
	Red shales and siltstones	100′
BASE	Coarse-grained red sandstones, minor fine red sandstone and siltstone	400′
	TOTAL THICKNESS	910′

The Bogan Gate Sandstone reaches its maximum thickness in this area. Southwards along the eastern limb of the Tullamore Syncline the basal red beds do not outcrop very well. Most of them have been removed by erosion and covered with alluvium. In the Weddin Range, the Bogan Gate Sandstone is 800 feet thick and unconformably overlies older Palaeozoic quartz sandstones and siltstones that strike at right angles to the Hervey Group and dip at angles of 80 degrees to the west. Small lenses or reworked limestones occur in the Bogan Gate Sandstone in this locality. These rocks are called calclithites and consist of many limestone fragments derived from older limestones from the basement rocks.

Three miles to the north of Bogan Gate, the Bogan Gate Sandstone is only two to three hundred feet thick and rests with a slight unconformity on the acid lavas of probable Lower Devonian age. Five miles to the north of Bogan Gate on the western limb of the Tullamore Syncline, the Bogan Gate Sandstone is only 100 feet thick.

No fossils have been found in the Bogan Gate Sandstone but sedimentary structures such as current bedding, ripple marks, and worm tracks and burrows are common.

THE NANGAR SUB-GROUP

The Nangar Sub-Group in the Tullamore-Weddin Range district can be subdivided into three formations, the Weddin sandstone, the Troffs Formation, and the Cloghnan Shale.

The Troffs Formation forms the basal formation of the Hervey Group in the Tullamore region. Relationships between the basal beds of the Troffs formation and older Palaeozoic rocks are hard to assess because of lack of good contacts in the field. North of The Troffs where the type section was measured, quartzose sandstones and calcarenites rich in shallow-water marine fossils, appear to be conformable with the lowermost quartzose sandstones of the Troffs Formation. Both sequences strike and dip at the same attitude, but there is an erosional gap that probably represents 500 feet of sediment

between the two sequences. The Troffs Formation is defined as the basal sandstone and shale formation of the Nangar Sub-Group in the Bogan Gate-Tullamore district. It consists mainly of fine-grained sandstones which do not make strike ridges as large as those of the Weddin Sandstone. It is conformably overlain by a shale formation which is called the Cloghnan Shale. The type section measured two miles to the north-east of the Troffs railway siding was as follows:

Top	Fine-grained white sandstones and siltstones	200′
	Erosion gap—probably fine sediments	? 300′
	Coarse-grained white sandstones, and flaggy white sandstones	60′
	Fine-grained white sandstones, with red siltstones..	150′
	Erosion gap, traces of fine-grained sandstone	100′
	Coarse-grained white sandstone, traces of brachiopods	130′
Base	Erosion gap	? 400′
	Total Thickness	1,340′

The Troffs Formation thins towards Bogan Gate. On the eastern limb of the Tullamore Syncline, north of Bogan Gate it is approximately 1,000 feet thick and on the western limb of the Tullamore Syncline to the west and north-west of Bogan Gate where it is 800 feet thick. To the south the Troffs Formation appears to thicken, however field relations are not clear in this area and it is possible that some of the sediments shown as the Troffs Formation may be infolded older Devonian basement sediments. The Troffs Formation thickens slightly towards the north and a thickness of 1,500 feet was measured near "Aurora Park" homestead east of Tullamore (column E, Fig. 5).

Traces of fish plates were found in upper sandstones of the Troffs Formation, four miles to the north-west of Bogan Gate and traces of brachiopods are commonly found in the basal sandstones in the Trundle district. Current bedding and current ripple marks are abundant and load casts are preserved on the lower faces of some sandstones.

The Cloghnan Shale: This formation conformably overlies the Troffs Formation. It is defined as a thick shale and siltstone sequence that lies between the lower sandstones of the Weddin Sandstone and the upper sandstones of the Troffs Formation. It makes very poor outcrops and is a very mappable formation in the Tullamore region where it makes a well marked valley between strike ridges of the Weddin Sandstone and the Troffs Formation. Because of its less resistant nature, it was impossible to find a complete succession to measure. The type area was taken in the vicinity of Cloghnan station about six miles north-east of The Troffs (Fig. 17). In this vicinity the Cloghnan Shale is approximately 600 feet thick and consists of very fine-grained sandstones, coarse siltstones and shales that vary in colour from green to red. The Cloghnan Shale thickens considerably to the north and is over 2,000 feet thick near the "Aurora Park" station homestead (column E, Fig. 5). The Cloghnan Shale thins towards the south and thicknesses between 200 to 400 feet are common in the Bogan Gate district. No fossils have been found in this formation. Ripple marks and small-scale current bedding are the most common sedimentary structures and generally occur in coarse siltstones.

The Weddin Sandstone

The Nangar Sub-Group cannot be subdivided into individual formations in the Weddin Range area where the Weddin Sandstone forms rugged sandstone cliffs 800 feet high. The following sequence was measured as the type section of the Weddin Sandstone, near Black Spring Mountain in the Weddin Range:

Top	Fine and medium-grained white and buff sandstones with inter-bedded green and white siltstones	400′
	Medium white sandstones, coarse sandstones interbedded with several 10′ to 20′ thick conglomerate layers ..	650′
Base	White and red sandstones, conglomerate, but many fine red and white sandstones and siltstones	450′
	Total Thickness	1,500′

The Weddin Sandstone thins slowly to the north, and is probably only 1,000 feet thick in the Wheoga Range although the upper parts of the sequence have been removed by erosion. Better outcrops occur in the ranges near Bogan Gate and east of Tullamore where the Weddin Sandstone forms prominent strike ridges.

The Weddin Sandstone makes large strike ridge outcrops in the Tullamore-Bogan Gate region. A section measured two miles north of Bogan Gate is 900 feet thick, consisting of medium to coarse-grained white sandstones with occasional pebbly and conglomerate layers. In the Tullamore region the Weddin Sandstone thickens considerably and is probably just over 2,000 feet thick in most sections (Fig. 5), although the upper parts of the outcrops are frequently removed by erosion. A conglomerate horizon is

present about 400 feet above the base of the formation and makes a good marker bed for mapping. This conglomerate is 10 to 50 feet thick and consists of pebbles of vein quartz, chert, and acid volcanic rocks. The pebbles range in size from quarter to one inch in diameter and are very well rounded.

Fish plates are found in this formation. Although no excellent specimens have been found, impressions of individual plates are fairly abundant and similar to types described by Hills (1932, 1935) from the Hervey's Range.

Current bedding measurements in coarse-grained sandstones of the Weddin Sandstone show a palaeocurrent from the west, north-west and north in the Bogan Gate-Tullamore district although palaeocurrents consistently come from the north in the Weddin Range area.

The Cookamidgera Sub-Group

Thick red measures that conformably overlie the white sandstones of the Weddin Sandstone have been correlated with the Cookamidgera Sub-Group. These red beds are characterised by very poor exposures and in most localities occur underneath alluvium-filled valleys in the synclinal axis of the Tullamore Syncline.

The thickness of these beds is estimated to be between 1,500 and 2,500 feet. Red siltstones are the most abundant sediment, and ripple marks, the characteristic sedimentary structure. No fossils have been found in these beds.

The Murda Syncline

The most western outcrop of Hervey Group sediments occurs in a large synclinal structure, called the Murda Syncline, that outcrops to the north of Condobolin. Outcrop distribution and stratigraphical columns measured from this area are shown on Fig. 5. The Murda Syncline is named after Murda Murda Creek that flows through the syncline throughout most of its length (Fig. 19). The geology of the Murda Syncline is shown on the geological map (Fig. 19) which has been prepared using air photos and field traverses. Once again, strike ridges of Upper Devonian sandstones make the most marked relief-forming features in an area of flat plains or slightly undulating country which is mainly formed of alluvium and poor outcrops of older Palaeozoic rocks. The relief caused by the strike ridges of the sediments of the Hervey Group is generally small, but some hard sandstone ridges such as the ridge that forms the Boona Mountain rise 500 to 600 feet above the surrounding plain (Fig. 19).

Geological sections across the Murda Syncline are shown on Fig. 20. The Murda Syncline is a broad open synclinal structure with minor folding on the northern limbs. The Murda Syncline shown on the geological map (Fig. 19) is 36 miles long, measured along the strike, and between 5 and 14 miles wide across the strike. The Murda Syncline extends several miles to the north and north-west of the area shown on Fig. 19. In general, the eastern limb of the syncline dips westward at angles of 30 and 20 degrees, while the western limb is somewhat steeper and dips at angles of 40 to 60 degrees to the east.

Erosion has removed large areas of outcropping rock particularly around Murda Murda Creek in the southern part of the syncline. Dips in the centre of the syncline are low and average between 5 and 15 degrees. Minor folding and faulting is common in the area between Campbells Tank and most northern extensions of the syncline. Faulting in the region of Boona Gap has brought older limestones of probable Silurian age against Upper Devonian sandstones. Large strike faults also occur in regions of tight folding south of Watson's Gap and also in the region of the southern nose of the Murda Syncline.

Raggatt (1937) made a regional investigation of the Condobolin-Trundle sistrict that has already been briefly discussed. Raggatt, in an unpublished report (1936), named the quartzites and sandstones of the Upper Devonian, the Boona beds. This name has been retained for the hard sandstones, now called the Boona Sandstone, that make strike ridges of the Boona Mountain. (Note : there is a formal description of a *Boonah Sandstone* formation in the Victorian Tertiary sequence (Raggatt and Crespin, *Proc. Roy. Soc. Vic.*, 67 (i) : 113).)

In most localities, the sediments of the Hervey Group rest unconformably on older regionally metamorphosed slates, phyllites and schists of probable Silurian or Ordovician age. To the north-west of the Murda Syncline outcrops the Wilmatha Granite which has been given a late Silurian age by Raggatt (1937). More recent alluvium and gravels have been subdivided into two groups by Raggatt (1937). The first is the Pleistocene and Recent alluvium of the Lachlan River and the second the Tertiary alluvial deposits and gold-bearing leads that were previously described by Morrison (1927) from the Fifield area to the east of the Wilmatha Syncline.

Stratigraphy

The stratigraphy of the Hervey Group in the Murda Syncline is illustrated on Fig. 5 in three

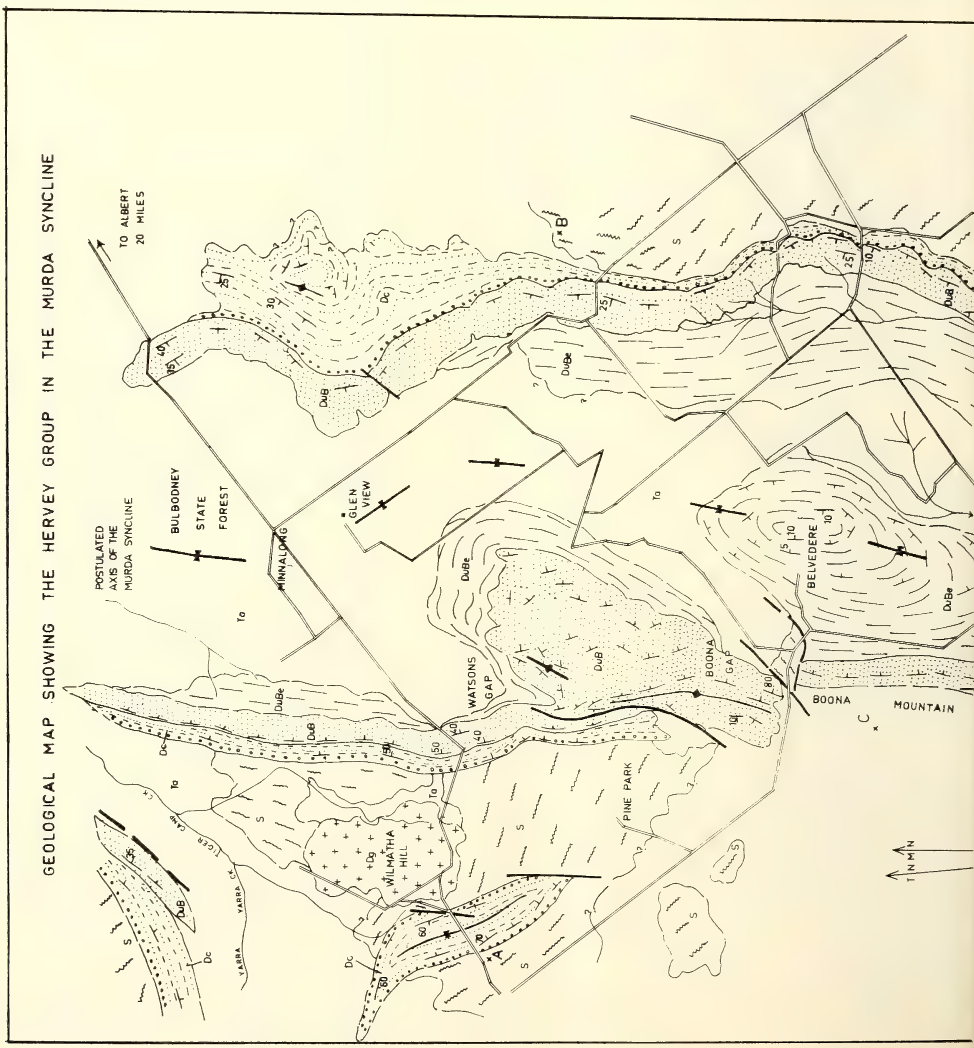
stratigraphical columns. The basal red beds of the Beargamil Sub-Group that are characteristic features of the Hervey Group elsewhere in central New South Wales do not outcrop in the Murda Syncline. Instead, there is a formation of poorly-sorted sandstones, thin conglomerates, and shales with poorly preserved marine fossils, which are herein grouped into the Condobolin Formation. Above the Condobolin Formation are the white sandstones and interbedded red and white siltstones of the Boona Sandstone which can be correlated with the Nangar Sub-Group. The uppermost formation is a red bed sequence called the Belvedere Formation, which is probably an equivalent of the upper red beds of the Cookamidgera Sub-Group.

Hence, although the base of the sequence is a marine, not an arkosic sequence, the formations conformably overlying the basal sequence correlate with the typical Hervey Group succession.

Traces of Lepidodendrid plant and fish plate remains have been found in the Boona Sandstone. Poorly preserved pelecypods, corals, and brachiopods in the Condobolin Formation are probably indicative of an older age than Upper Devonian, and may be correlated with the " Ampitheatre Stage " (Lower to Middle Devonian) in the Cobar region to the west of Condobolin (Mulholland, 1940).

The Condobolin Formation

The Condobolin Formation is the basal formation of the Devonian sequence in the Murda Syncline. Raggatt (1937) subdivided the



GEOLOGICAL MAP SHOWING THE HERVEY GROUP IN THE MURDA SYNCLINE

Devonian sequence in the Condobolin district into four units. The upper unit is defined as the Boona Sandstone in this report and the lower three units are grouped into the Condobolin Formation.

The Condobolin Formation consists of interbedded shales, siltstones, sandstones and conglomerates. In some localities conglomerate beds are abundant towards the base of the formation, particularly to the west of Wilmatha Hill where the Condobolin Formation forms outcrops in a synclinal structure away from and to the west of the main Murda Syncline (Fig. 19).

In other localities, however, and particularly in the southern regions of the Murda Syncline conglomerate beds occur sporadically throughout the sequence and do not form distinct basal horizons.

The Condobolin Formation forms a sequence which is generally much softer than the Boona Sandstone and is poorly exposed.

The type section was measured approximately six miles north of Condobolin on the eastern limb of the Murda Syncline. Here outcrops are bad, but the following subdivisions were estimated:

Top	Green and red shales, red siltstone, some thin sandstone members	300′
	Conglomerate beds with pebbles of vein quartz and chert, quartz-rich but poorly-sorted sandstones, interbedded shales and siltstones	400′
	Poor exposures, siltstones and shales the dominant lithology, some thin conglomerate and sandstone beds ..	300′
Base	.. ..	1,000′

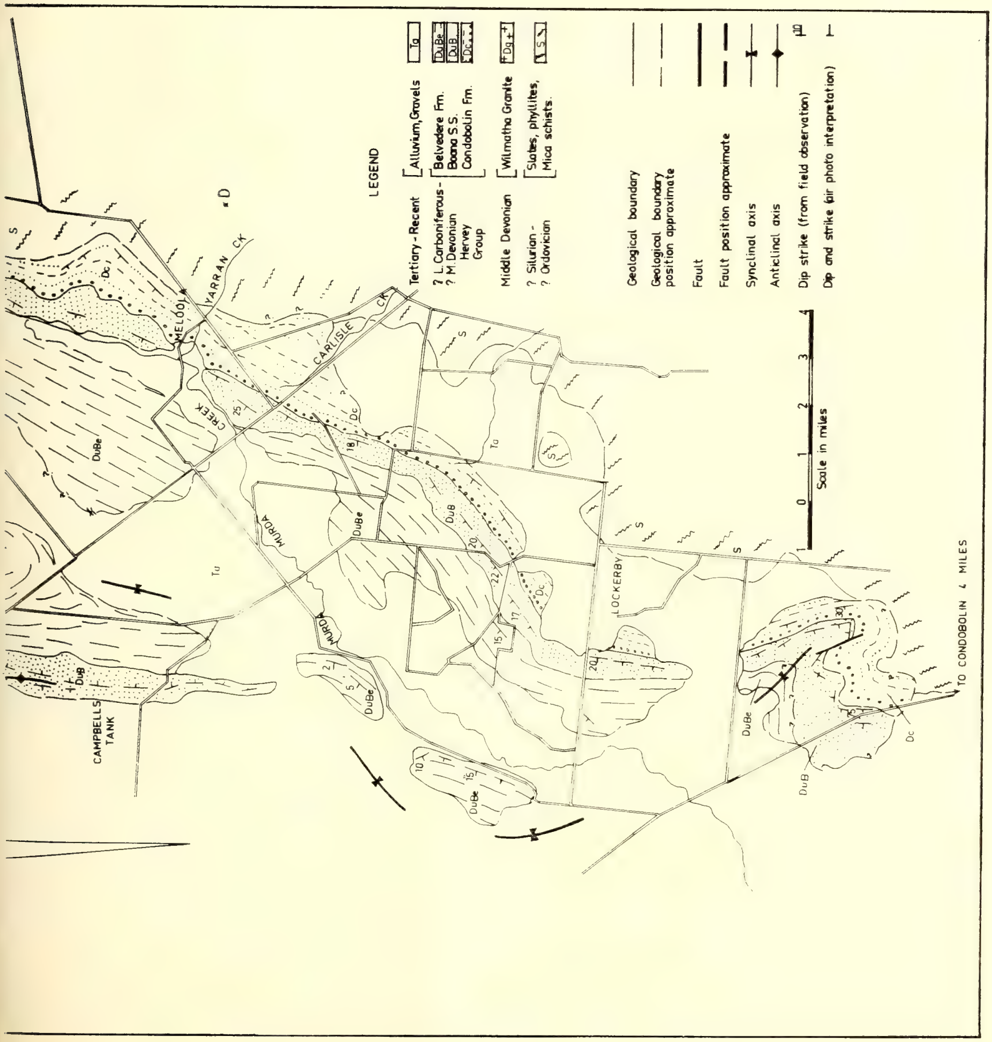


Fig. 19

stratigraphical columns. The basal red beds of the Beargamil Sub-Group that are characteristic features of the Hervey Group elsewhere in central New South Wales do not outcrop in the Murda Syncline. Instead, there is a formation of poorly-sorted sandstones, thin conglomerates, and shales with poorly preserved marine fossils, which are herein grouped into the Condobolin Formation. Above the Condobolin Formation are the white sandstones and interbedded red and white siltstones of the Boona Sandstone which can be correlated with the Nangar Sub-Group. The uppermost formation is a red bed sequence called the Belvedere Formation, which is probably an equivalent of the upper red beds of the Cookamidgera Sub-Group.

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The Condobolin Formation

The Condobolin Formation is the basal formation of the Devonian sequence in the Murda Syncline. Raggatt (1937) subdivided the Devonian sequence in the Condobolin district into four units. The upper unit is defined as the Boona Sandstone in this report and the lower three units are grouped into the Condobolin Formation.

The Condobolin Formation consists of interbedded shales, siltstones, sandstones and conglomerates. In some localities conglomerate beds are abundant towards the base of the formation, particularly to the west of Wilmatha Hill where the Condobolin Formation forms outcrops in a synclinal structure away from and to the west of the main Murda Syncline (Fig. 19).

In other localities, however, and particularly in the southern regions of the Murda Syncline conglomerate beds occur sporadically throughout the sequence and do not form distinct basal horizons.

The Condobolin Formation forms a sequence which is generally much softer than the Boona Sandstone and is poorly exposed.

The type section was measured approximately six miles north of Condobolin on the eastern limb of the Murda Syncline. Here outcrops are bad, but the following subdivisions were estimated:

Top	Green and red shales, red siltstone, some thin sandstone members	300′
	Conglomerate beds with pebbles of vein quartz and chert, quartz-rich but poorly-sorted sandstones, interbedded shales and siltstones	400′
	Poor exposures, siltstones and shales the dominant lithology, some thin conglomerate and sandstone beds ..	300′
Base	.. ..	1,000′

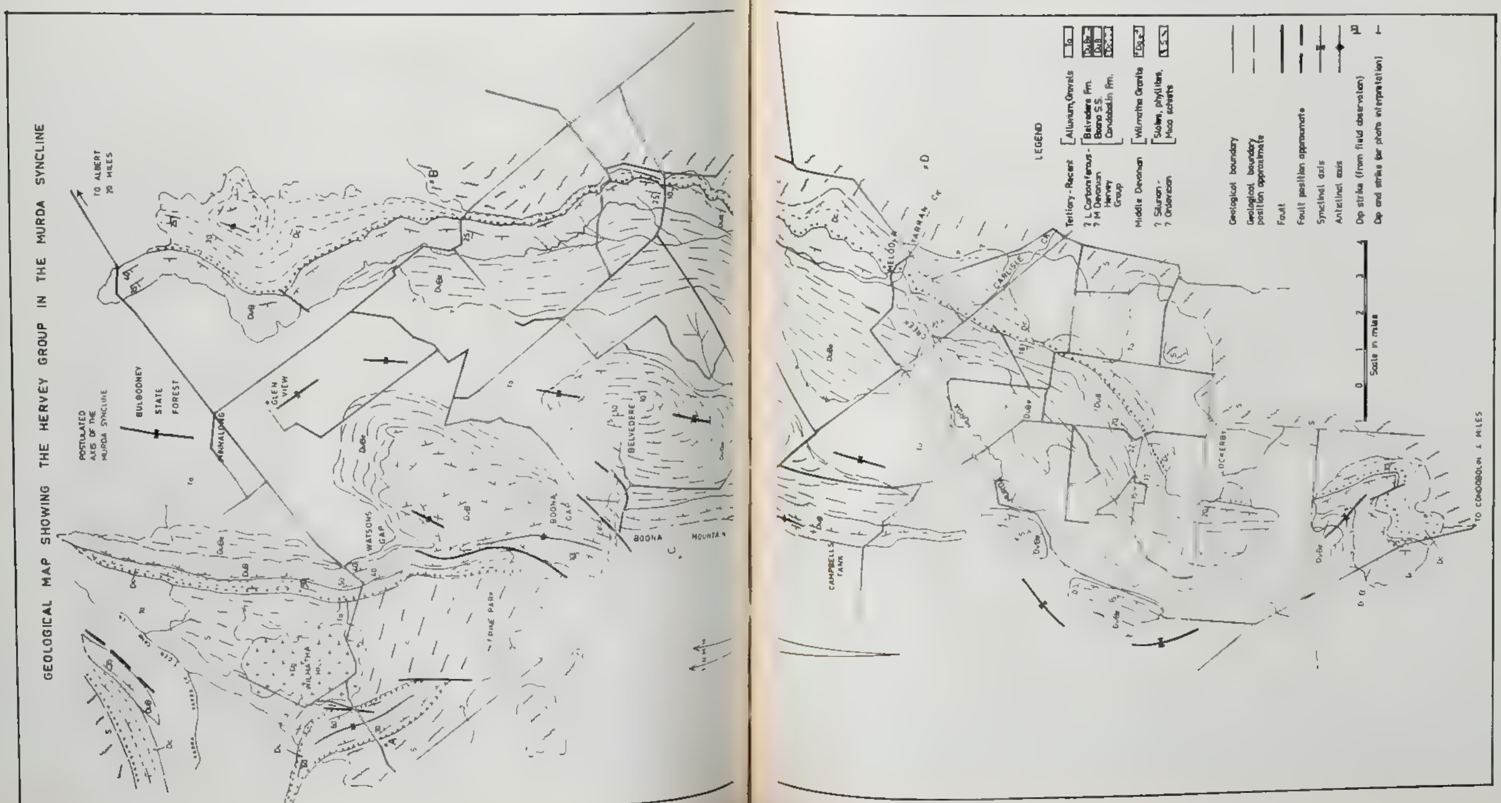


Fig. 19

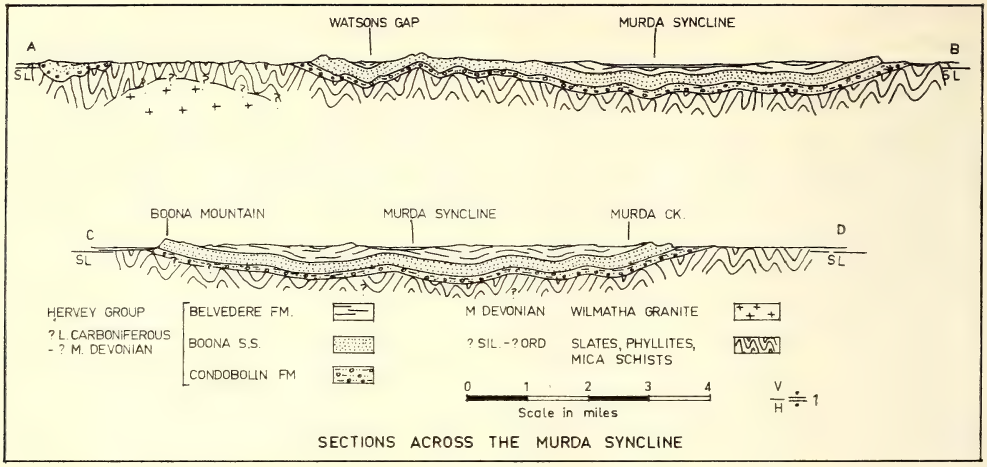


FIG. 20

Rapid changes in thickness are characteristic of the Condobolin Formation and along the eastern limb of the Murda Syncline the thickness of the Condobolin Formation varies from 200 feet to 1,500 feet.

The boundary of the Condobolin Formation with older Palaeozoic basement rocks can be easily seen due to differences in vegetation on air photos. Estimates of the thickness of the Condobolin Formation show that it varies considerably in thickness and facies. The Condobolin Formation has a thickness of over 2,000 feet in the Yarra Yarra Creek area 6 miles to the north-west of Wilmatha Hill. In this locality, thin limestone beds occur interbedded in a sequence which consists of shales, sandstones and conglomerates. Species of brachiopods probably belonging to the genus *Spinella* are abundant throughout the limestone and may be indicative of a Middle Devonian age.

The faunas described from the lower units of the Devonian in the Condobolin district by W. S. Dun have been ascribed to the top of the Middle Devonian or to the base of the Upper Devonian by Dr. F. W. Booker (in Raggatt, 1937). However, since the sediments of the Condobolin Formation are conformable with the overlying Upper Devonian Sandstones of the Boona Sandstone they have been included in the Hervey Group.

The Boona Sandstone

The Boona Sandstone is a sandstone formation conformably overlying the Condobolin Formation. The entire Upper Devonian sequence including the Boona Sandstone and the overlying red beds of the Belvedere Formation was originally called the Boona Beds in an unpublished report by Raggatt (1936).

The name Boona Sandstone has now been restricted to the sandstone formation that makes the strike ridges of the Boona Mountain on the western limb of the Wilmatha Syncline. In this locality the Boona Sandstone consists of 1,500 feet of interbedded white sandstone, white grits, and thin red sandstone and red silt stone members. Along the eastern limb of the Wilmatha Syncline the Boona Sandstone thickens 1,000 feet in the south to 1,750 feet in the north (columns C to A, Fig. 5). Current bedding measurements in the eastern limb show palaeocurrents from the north-west and south-west. The only fossils found were poorly preserved traces of Lepidodendrid plants and fish plates and probably indicative of an Upper Devonian age.

The Belvedere Formation

The Belvedere Formation conformably overlies the Boona Sandstone. It consists of a thick sequence of red beds which normally form poor outcrops, but which form reasonably good outcrops near the " Belvedere " station property, about 25 miles north of Condobolin (Fig. 19).

In the type area, on the " Belvedere " station property, the red sandstones of the Belvedere Formation make a large basin structure in the axial region of the Murda Syncline. Dips are shallow within this structure and minor folding may be present of the outer edges of it. Between the upper red sandstones of the Belvedere Formation which make the outcrops near " Belvedere " homestead and the sandstones of the Boona Sandstone, there is a large poorly outcropping area of red shales and siltstones

These finer red sediments form the lowermost sequence of the Belvedere Formation. Their thickness is estimated at 400 to 600 feet. The upper sequence of sandstones is 500 feet thick near Belvedere, making the total estimated thickness in the type area of at least 1,100 feet.

The upper sandstones are also well preserved in strike ridges along the western side of Murda Murda Creek as it flows southwards towards Condobolin. Estimated thickness of the Belvedere Formation in other areas of the Wilmatha Syncline vary from 600 to 1,100 feet. Traces of fish plates have been found in the Belvedere Formation in the type area and sedimentary structures such as ripple marks and current bedding are common.

CORRELATION AND STRATIGRAPHIC SUMMARY OF THE HERVEY GROUP

It has been shown that the Hervey Group characteristically consists of three main lithological sequences which have been grouped into three Sub-Groups, the Beargamil, Nangar and Cookamidgera Sub-Groups. Figures 4 and 5 show the correlation of these Sub-groups from one measured column to another.

Except in the Murda Syncline and in the Tullamore district, the basal sequence of the Hervey Group consists of red measures. These red measures vary considerably in mineralogical and fragmental rock content (Conolly, 1962) but all are indicative of an arkosic type of sedimentation. The basal red-bed formations of the Beargamil Sub-Group can be correlated with one another because of their position in the sequence and their similar types of lithology. The overlying sediments have an Upper Devonian age, hence it seems a permissible assumption that these red beds are the basal formations of an Upper Devonian sequence.

The Nangar Sub-Group consists of a sequence of formations which are either dominantly sandstone, or red siltstones, or a succession of both of these lithologies. Rapid changes in thickness and lithology in this Sub-Group not only make correlation difficult, but also make the definition of actual formation boundaries difficult. Hence, it has been necessary to define the upper and lower surface of formations in an arbitrary manner. For instance, the Mandagery Sandstone is the basal formation of the Nangar Sub-Group and its lower boundary is defined as the first thick massive white sandstone above the red beds of the underlying Beargamil Sub-Group.

The upper boundary of the Mandagery Sandstone is also an arbitrary one and coincides with the last massive white sandstone bed underlying a thick sequence of red siltstones or finer-grained sediments. The entire succession of the Nangar Sub-Group is essentially similar and consists of repetitions of the cycle, white quartzose sandstones, red and white sandstones with some red siltstones, and then red siltstones. When the first member of this cycle, that is, the quartzose sandstone member, is developed as a mappable sequence it has been given a formation name. Similarly the red siltstones of the upper cycle also frequently form a mappable formation. It is in this manner that the Nangar Sub-Group has been subdivided. Hence, in the eastern area of outcrop shown on Fig. 4 the basal formation of the Nangar Sub-Group is a quartzose sandstone formation called the Mandagery Sandstone. In the western area of outcrop shown on Fig. 5, the Weddin Sandstone and the Boona Sandstone are equivalent sandstone formations to the Mandagery Sandstone but do not always occur immediately above basal red beds.

Since the Mandagery, Boona, and Weddin Sandstones are similar in lithology, normally overlie basal formations of the Hervey Group, and all contain traces of a Bothriolepid fish-plate assemblage, it seems feasible to make a tentative correlation of these three formations with one another.

Correlation of formations above the Mandagery Sandstone in the eastern area of outcrop in the Nangar Sub-Group is not so easy. It is normal to find a rhythmic succession of red and white measures after the first white sandstone formation of the Nangar Sub-Group. Some of these red or white sequences may be regarded as lithological units and are given formation names, while in other areas several such units are grouped together into one formation. For instance, in the Manildra-Gooloogong region, the first thick red siltstone and fine-grained red sandstone formation is called the Pipe Formation. This formation contains many thin beds of white sandstone and red siltstone. On the other hand, further south in the Gooloogong-Grenfell region, the formation that has an identical position in the sequence as the Pipe Formation, the Hunter Siltstone, consists almost entirely of red siltstones. Hence if these two formations have been laid down at similar times then there is a distinct facies change between the two areas.

Although sequences similar to those of the Pipe Formation and Hunter Siltstone are fairly consistent over a small area (10 to 20 miles), they are inconsistent over larger areas, making

it impossible to make positive correlations in the upper horizons of the Nangar Sub-Group on lithological grounds. Fossils are also of not much help in the upper formation of the Nangar Sub-Group. Many of these formations have a Lepidodendrid assemblage but the Bothriolepid assemblage is not so abundant.

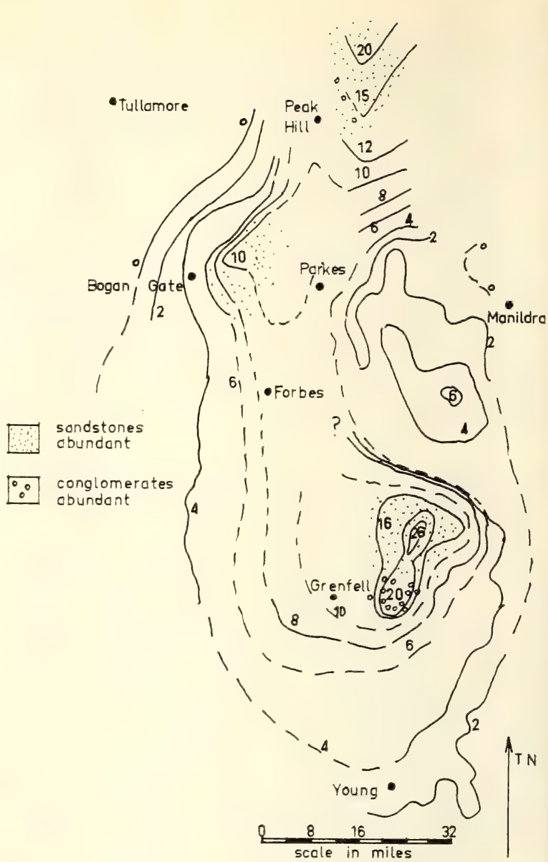
In the western area of outcrop shown on Fig. 5, the Weddin Sandstone has been tentatively correlated with the Boona Sandstone. Underlying both of these formations in the Condobolin and Bogan Gate-Tullamore districts is a sequence of interbedded sandstones, siltstones and sometimes thin beds of conglomerate in which traces of marine fossils are common and which may be indicative of a Middle Devonian or lower Upper Devonian age. It seems feasible to correlate these sequences, namely the Condobolin Formation, in the Condobolin district, and the Troffs Formation in the Bogan Gate-Tullamore district with one another.

The upper red measures of the Hervey Group which have been called the Cookamidgera Sub-Group have been preserved in many areas. Several problems arise in the correlation of this Sub-Group. It seems that the rhythmic red and white sedimentation typical of the Nangar Sub-Group always terminates with a terrestrial sequence of red beds which has been called the Cookamidgera Sub-Group. However, these uppermost red bed sequences may only correspond to thick red bed cycles of the Nangar Sub-Group. As most of these beds are extremely thick, much thicker than any of the red bed sequences that occur interbedded in the Nangar Sub-Group, it seems more reasonable to put the upper red bed sequences of the Hervey Group into a separate Sub-Group.

Figures 4 and 5 show that the measurable thickness of the Hervey Group varies considerably. The largest thickness occurs in the Parkes Syncline, where there is over 9,000 feet preserved, and the maximum recorded thickness in most other areas varies between 4,000 and 8,000 feet. The variation in thickness and lithology is best studied at the level of Sub-Groups and formations which can be correlated from one area to another.

The Beargamil Sub-Group

Figure 21 is an isopach map of the Beargamil Sub-Group in central New South Wales. Although readings of thickness were not available in some areas because of lack of outcrop, the isopach map clearly indicates that the Beargamil Sub-Group was not deposited any further west of the Tullamore-Bogan Gate region, and probably not further east than Manildra and not much further south than Young. To the north-east of Peak Hill there is a great thickness of basal red beds which is thickening steadily to the north. Other areas where a large thickness of sediment was deposited occur just to the east of Grenfell and just to the east of Bogan Gate.



ISOPACH MAP OF THE BEARGAMIL SUB - GROUP IN CENTRAL NEW SOUTH WALES (isopachs in hundreds of feet)

Fig. 21

The areas of greatest thickness are also the areas with the coarsest sediments. From an inspection of the isopach map, it can be easily seen that the coarsest and thickest basal red bed sequences were laid down along a line that runs from near Grenfell north and slightly west towards Bogan Gate and then north and slightly east towards Peak Hill. The sequence thins steadily from these areas towards the south, west and south-east, but fluctuations in thickness are present in the north-east. The Beargamil Sub-Group was deposited in a

trough-like area closed at its eastern, southern and western ends. The thickest accumulation of sediment took place along the central portion of this area with the deposition of conglomerates and coarse sandstones, as well as finer-grained sediments.

The Nangar Sub-Group

Problems of correlation make it difficult to reconstruct changes in lithology and thickness over any great lateral extent. The only sequence of beds that can be correlated throughout the area of deposition is the sequence of white orthoquartzites containing *Bothriolepis* that occurs immediately above the Beargamil Sub-Group, in the east and overlying marine formations in the west. Figure 22 is an isopach map of this series of sandstone formations, namely the Mandagery, Weddin and Boona Sandstones.

The thickest accumulations of sediment took place to the north of Tullamore and in a separate basin to the north-east of Forbes. The sediments thin steadily to the east, indicating that a zero isopach could probably be found in that direction. The sediments also thicken steadily to the north in the Tullamore-Condobolin region. A ridge structure is present between Peak Hill and Forbes, where very little sediment was deposited. This ridge may probably correspond to an area in which siltstone sedimentation was greater than the sandstone sedimentation that makes this cycle.

One of the most important features shown by this isopach map is the non-appearance of any zero isopach line. In particular, the only trend that indicates the presence of such a line would be to the east. To the west, south, and north, however, deposition must have continued for some distance out of the area shown on Fig. 22. Figure 22 also shows the presence of a basal conglomerate facies along the south, south-western and western portions of the area, and an area to the west and south of Grenfell where conglomerates were abundant. Finer-grained sandstones occur more frequently to the north-east. Hence, there is a facies change from fine-grained sandstone and siltstone in the north-east to sequences with abundant conglomerates in the west and south.

Figure 23 is a palaeocurrent diagram showing the palaeocurrent directions for the Nangar Sub-Group sediments. The directions shown on this diagram were obtained from many hundreds of current bedding readings. Twenty to thirty readings were taken in each locality before the palaeocurrent direction was calculated. Generally, palaeocurrents came from the west and as they approached the eastern area of deposition, swung southwards towards Young. South-east of Peak Hill there are some readings that indicate a local palaeocurrent from the south-east.

The thinning of the first orthoquartzite formation to the east and the abrupt swing in palaeocurrent direction when it reaches the east indicates that there may have been some barrier or high area to the east impeding deposition. Currents were probably strongest in the south near Young and along the western margin of the area shown on Fig. 23, where the conglomerate facies (mentioned above) was deposited.

The sediments of the Nangar Sub-Group above the first otrhoquartzite cycle attain large thicknesses wherever they are preserved. There are not enough data available to enable the construction of an isopach map, but some general conclusions can be made by studying the changes in thicknesses and lithology as shown on the correlation diagrams (Figs. 4 and 5).

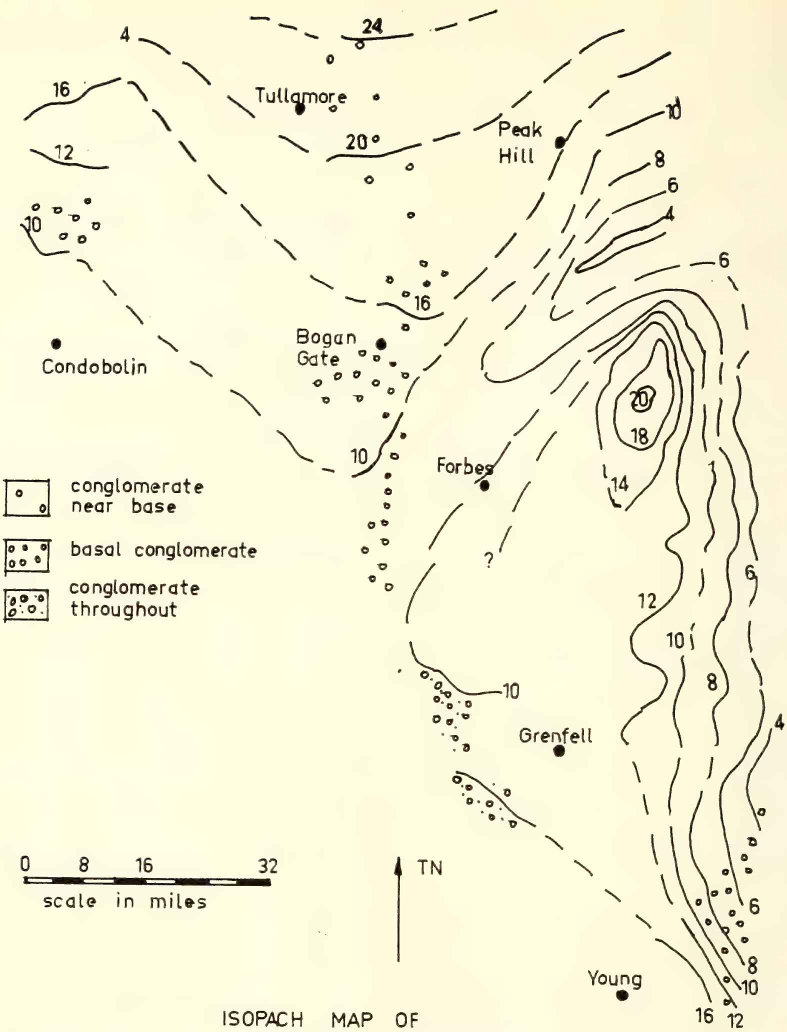
Whereas the lower orthoquartzite cycle in the Nangar Sub-Group thinned to the east, the upper formations thicken. Coarse sandstones and conglomerates are also present in the upper formations in the eastern area, but have not been found in any other areas. It seems that the sediments of the upper Nangar Sub-Group are essentially a sequence of cycles of red and white beds which thicken, and transgress the thin basal orthoquartzites to the east, but which thin to the west.

The Cookamidgera Sub-Group

The last phase of sedimentation that is preserved is a red-bed sequence consisting of red fine-grained sandstones, red siltstones, and red mudstones. This sequence, called the Cookamidgera Sub-Group, represents a thick sequence of red measures overlying the Nangar Sub-Group. Variation in thickness and lithology cannot be estimated, since erosion has removed most of the outcrops.

Sedimentation

The palaeogeography and sedimentation of the Upper Devonian rocks of the Lachlan Geosyncline have been reviewed by the author (Conolly, 1964). In this review petrological results were used as an aid to correlation and to the interpretation of provenance. The sedimentation of the Hervey Group was described for three time periods. A similar brief review will be described in this section



ISOPACH MAP OF
THE 'BOTHRIOLEPIS' BEARING ORTHOQUARTZITE CYCLE IN THE NANGAR SUB - GROUP IN CENTRAL NEW SOUTH WALES
includes the Boona S.S., Weddin S.S. - and Mandagery S.S.,

isopachs in hundreds of feet

Fig. 22

on the assumption that the correlations made for the time periods previously proposed are still valid, and by grouping the Upper Devonian and Lower Carboniferous into a single unit of time.

1. Late Middle Devonian–Early Upper Devonian

It is assumed that the bulk of the formations of the Beargamil Sub-Group, the Troffs Formation in the Tullamore-Bogan Gate district, and the Condobolin Formation in the Condobolin district were deposited during this period. Briefly, the sedimentation during this period based on the above assumption is as follows :

Arkosic and lithic sandstones, red siltstones and mudstones were deposited on a fairly flat, low, undulating surface of older rocks. These rocks consisted of large areas of granite, fairly flat-lying acid and intermediate volcanics, and smaller areas of folded quartz-rich sediments. These basal " arkosic " rocks were deposited in

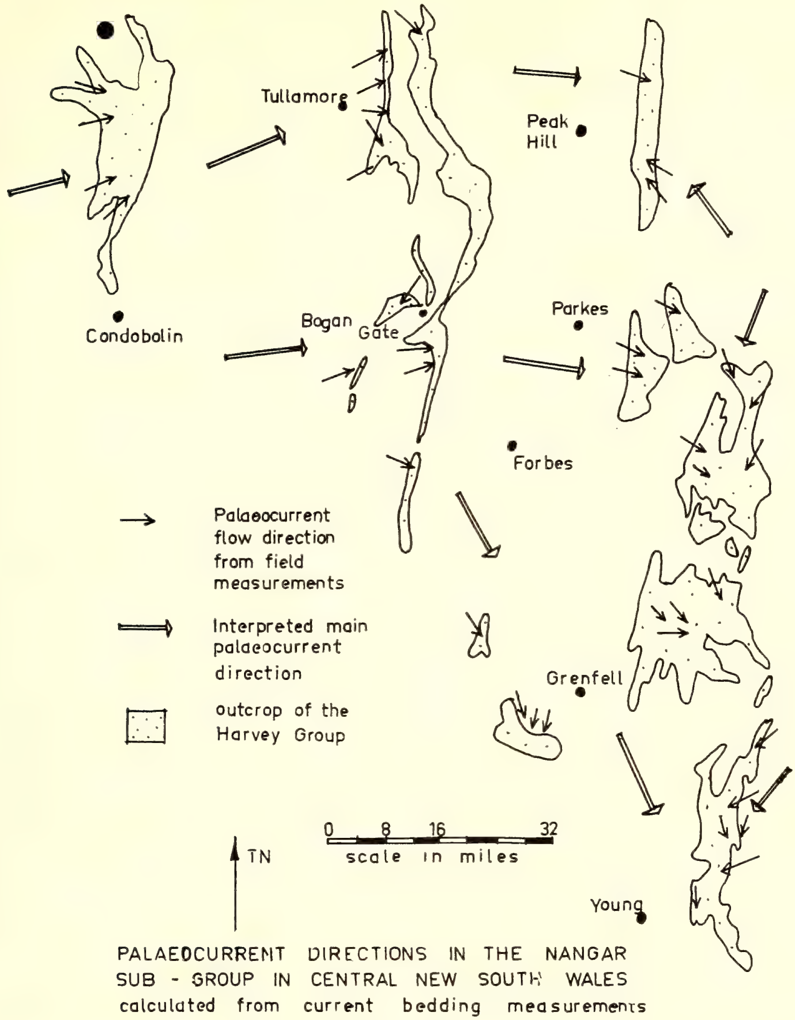


FIG. 23

an area confined by the isopachs shown on Fig. 21. The thickest accumulation of sediment took place in a trough-like area in the Grenfell district, where conglomerates are a characteristic feature of the basal sequence. Most of the deposits thickened or thinned into local basement highs and wedge-shaped deposits were commonly formed. The sediment was carried into the area by a large stream system which probably fed from a southern land mass and the sediments were deposited on an alluvial plain.

The sea flanked this land area to the east near Wellington (Conolly, 1963), and to the north-west in the Tullamore-Condobolin district. In these areas, sandstones, shales, siltstones and conglomerates were deposited in environments which probably fluctuated from estuarine to marine shelf.

2. UPPER DEVONIAN TO LOWER CARBONIFEROUS

The remainder of the sediments of the Hervey Group overlying the basal formations was very probably deposited throughout the Upper Devonian and into the Lower Carboniferous. The nature of the sedimentary structures such as current bedding, the cyclic mode of deposition, the abundance of plant and fish remains clearly suggest that the rocks were deposited in a terrestrial environment.

The palaeocurrent directions shown on Fig. 23 suggest that the rivers carrying the sediments flowed from the west near Condobolin and Tullamore and then flowed southwards in the Parkes or eastern area of deposition. It appears that the rivers may have flowed around a land barrier which existed south of Condobolin.

Deposition of the cycle, coarse sandstone, followed by sandstones and siltstones, and then by siltstones and mudstones, is probably typical of the cycles deposited by a large meandering river. The coarse deposits are deposited in the areas of the strongest currents. As the banks of the river are cut away, then the location of the strongest currents and hence the location of the deposition of the coarse sediments move. The coarse deposits are eventually covered by the fine-grained sands and silts of the point-bar deposits and then these in turn by the silts and muds of the flood plain. Rapid changes in thickness and lithology so prevalent in the Nangar Sub-Group are a characteristic feature of these deposits. Apart from normal river and flood-plain sediments, silts and muds were probably also deposited in large inland lakes or swamps.

Acknowledgements

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Explanation of Plates

PLATE I

Looking eastwards towards the Hervey's Range from a locality six miles east of Peak Hill. The Caloma Trig. is the highest peak in the range, approximately 1,800 feet higher than the surrounding plain and distant three miles from the immediate foreground of the photograph. The portion of the Hervey's Range in this photograph shows easterly-dipping strike ridges (from the closest ridge) of the Clagger Sandstone, Mandagery Sandstone, and the Caloma Sandstone. The Kadina Formation and the Pipe Formation form low hills and valleys between the ridges of the sandstone formations. The Clagger Sandstone and the Kadina Formation dip steeply to the east, the Mandagery Sandstone and Pipe Formation dip more gently to the east and the Caloma Sandstone has sub-horizontal dips to the east. Recent deposits of boulder drift and alluvial gravels occur at the front of the range.

PLATE II

1. Spillway of Lake Endeavour Dam, Bumberry Syncline east of Parkes looking eastwards towards the dam wall. Planar and current bedding units of the Mandagery Sandstone dip at a shallow angle to the east. A current-bedded unit on the left centre of the photograph reaches thicknesses of four feet and is overlain by planar beds of sandstone, six inches to two feet thick.

2. Spillway of Lake Endeavour Dam, Bumberry Syncline east of Parkes looking eastwards down the plunge of a basin-shaped current-bedded unit of the Mandagery Sandstone. This unit is typical of the style of current bedding within the Mandagery Sandstone. Measurements of the dips of the current bedding will normally be always in the direction of the plunge of basin. In this locality, these dips indicate palaeocurrents that flowed from west to east. The tape measure resting on the upper surface of the current-bedded unit in the foreground of the photograph is approximately six inches in diameter.

3. Spillway of Lake Endeavour Dam, Bumberry Syncline, east of Parkes, looking eastwards. Uniformly bedded fine-grained white orthoquartzites of the Mandagery Sandstone dip towards the east at 10°. The thickness of the beds of sandstone varies between six inches and two feet.

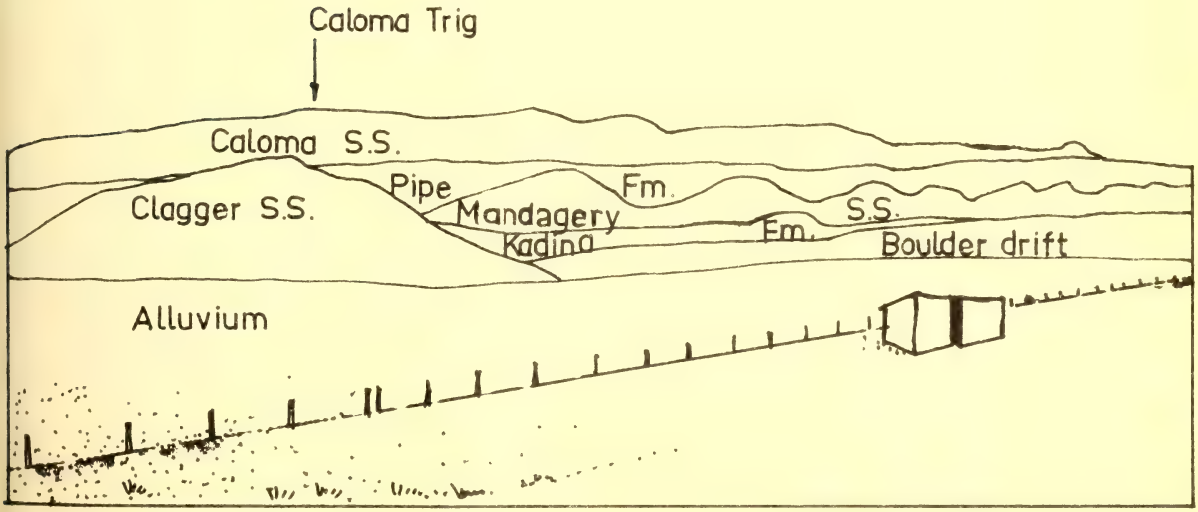
4. Spillway of Lake Endeavour Dam, Bumberry Syncline, east of Parkes, looking north-eastwards. Lenticular and arched beds of Mandagery Sandstone overlying planar beds. Some beds show evidence of movement due to slumping after deposition, but prior to the deposition of overlying beds. The sledgehammer in the centre of the photograph is approximately three feet in length.

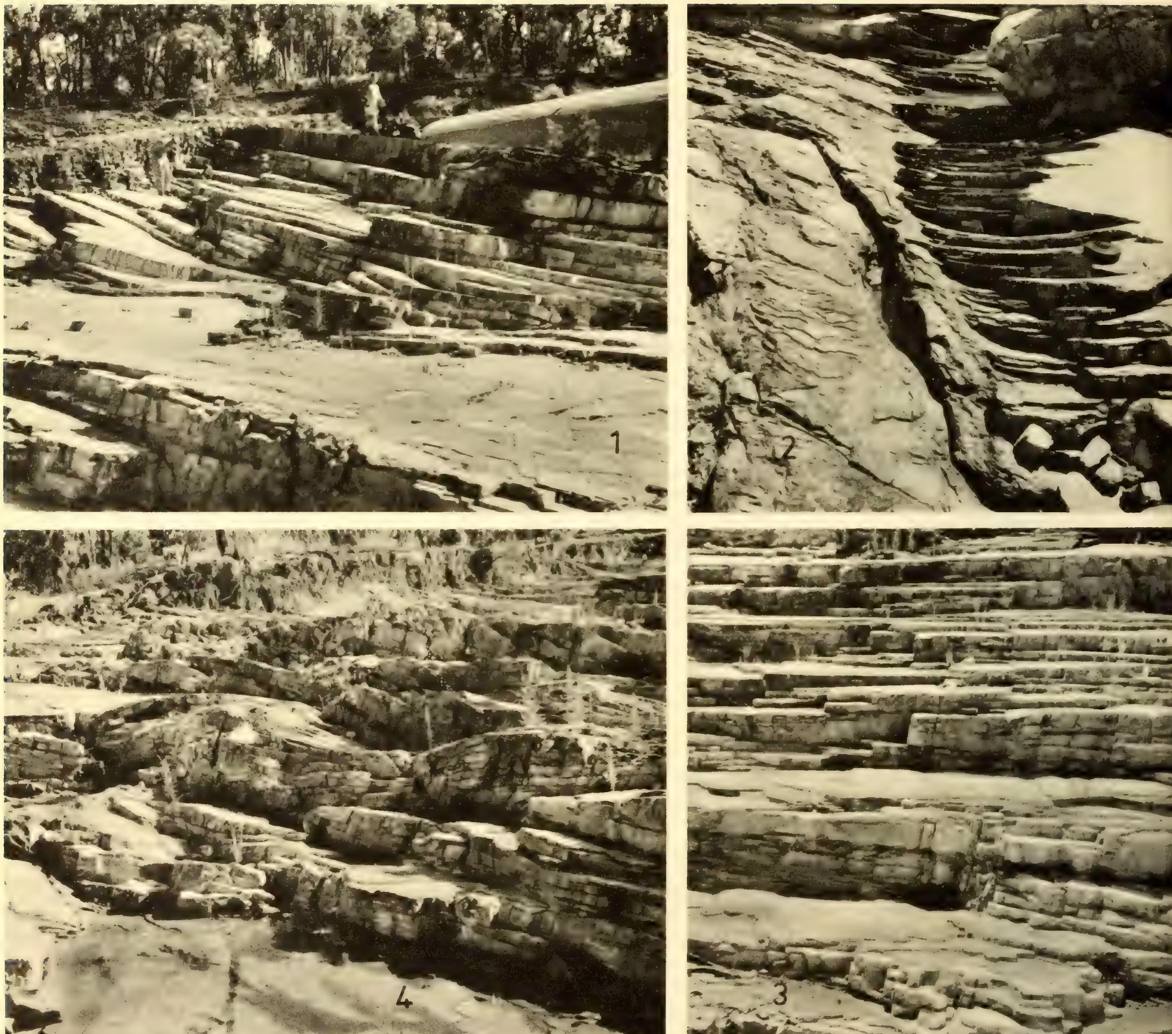
PLATE III

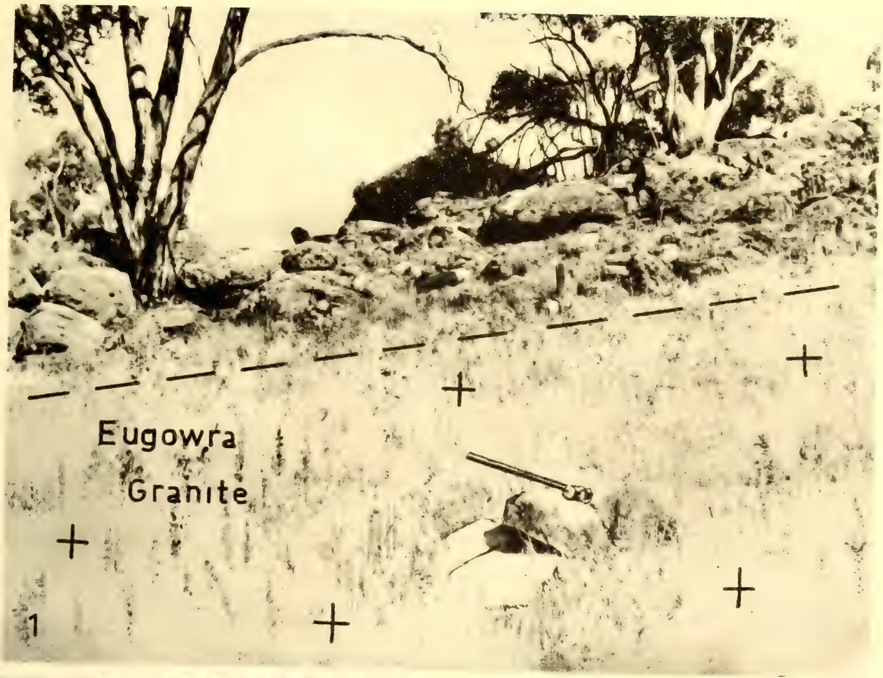
1. Four miles south-west of Gooloogong, looking eastwards at the basal sandstone beds of the Peaks Sandstone. These beds are coarse-grained red grits and pebbly sandstones forming the basal beds of the Hervey Group. The sandstones are quartzose and fragments of acid volcanics are fairly abundant. However, they unconformably overlie the Eugowra Granite. A boulder of this granite outcrops some 15 feet from the massive outcrop of the Peaks Sandstone. A sledgehammer is resting on this granite outcrop in the immediate foreground of the photograph.

2. Spillway of Lake Endeavour Dam, in the Bumberry Syncline, east of Parkes, showing slumped beds of Mandagery Sandstone. Two slump units can be seen, an upper large unit and a lower smaller unit near the lower right-hand edge of the photograph. The individual sand layers of the slumps rarely show any convolution or fracturing but form symmetrically arranged folds with a common fold axis.

3. Same locality as 2, showing the smaller slumped unit in 2 ; the tape measure is marked in inches.


Caloma Trig
Caloma S.S.
Clagger S.S.
Pipe
Fm.
Mandagery
S.S.
Kadina
Fm.
Boulder drift
Alluvium




Eugowra
Granite
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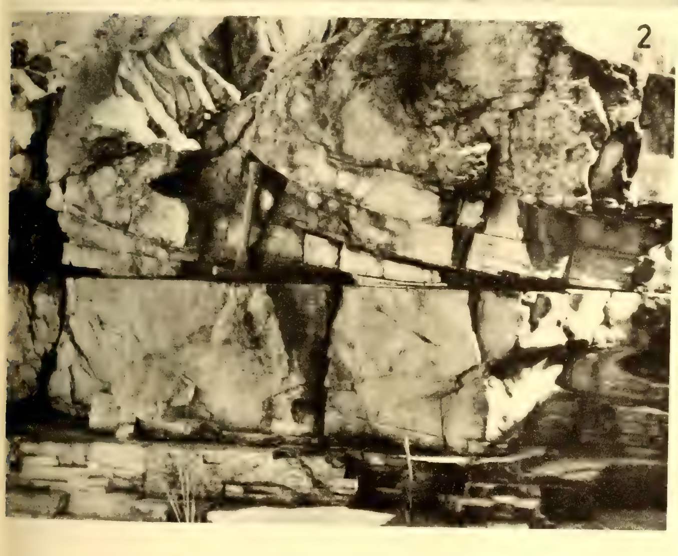
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A Note on the Stratigraphy of the Devonian Garra Beds of New South Wales

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Abstract—The reconnaissance name " Garra Beds ", introduced by Joplin and Culey (1938) for the southern portion of a belt of Devonian limestones near Molong and Wellington, N.S.W., is formally replaced by the name " Garra Formation ". The formation consists of reef and detrital limestones and shales, whose lateral and vertical relationships are highly complex. Because of this complexity, the discontinuity of outcrops, and the presence of extensive folding and strike faulting, it has not been possible to subdivide the formation.

Overlying the limestones are sandstones and shales of the Upper Devonian Catombal Group ; the junction is commonly gently unconformable. Conformably beneath the limestones is a succession of sediments and volcanic rocks extending well down into the Silurian.

The formation is probably either upper Lower or basal Middle Devonian in age.

Introduction

The purpose of this Note is to provide a formal definition of the Devonian limestone outcrops of the Molong-Wellington region of N.S.W., limestones which have hitherto been known as the " Garra Beds ". These rocks crop out in a linear tract some 60 miles in length, and up to five miles in width. This tract extends southward from the vicinity of Geurie, past Wellington and Molong, almost to Cudal (see Text-fig. 1).

Matheson (1930) was the first to publish a map showing some of these limestones, but the first detailed work was done by Joplin and Culey, who (1938) published the name " Garra Beds " for the Devonian limestones and shales west and south of Molong. Basnett and Colditz (1946), in mapping the Dubbo-Wellington region, recorded a northern extension of the Beds, to the west of Wellington. Joplin and others (1952) compiled a map based on all the available information for the region of the Molong Geanticline, including work done by honours students within the University of Sydney. Finally, the southernmost outcrops of the Beds were included in the map published by Walker (1959).

Palaeontological research on the abundant fossils of the Garra Beds began with the work of Etheridge jr. (1895, 1898*a*, 1898*b*, 1903, 1907). Later papers, all on corals, are : Hill (1942), Hill and Jones (1940), Jones (1944) and Jones and Hill (1940). Packham (1954) described a new *Hadrophyllum*, Ross (1961) included four polyzoan species in her study of Australian Palaeozoic Polyzoa, and lastly Strusz (1964) described several trilobites.

The present Note stems from a detailed study of the Garra Beds, and is a preliminary to several papers dealing with the taxonomy of the numerous corals collected during that study. It is proposed to designate the Beds as a Formation, consisting of a complex of limestones and detrital beds of variable calcareous content, the whole being the deposits associated with an area of reef development. It was found that outcrops presented a bewildering picture of facies and thickness variation. It has not proved possible to subdivide the rocks into clearly defined units, because in most areas the outcrops are sporadic. Because of this outcrop discontinuity, in many places individual strata could not be traced around the numerous folds, nor correlated across the many faults.

It is nevertheless clear that the Garra Beds are readily distinguishable from the units above and below, and can be mapped as a unit. Their designation as a formation is therefore a desirable step in the study of the stratigraphy of this part of the Tasman Geosyncline.

Formal Definition

Location, name : The Garra Formation takes its name from the village of Garra, on Mandagery Creek some $6\frac{1}{2}$ miles west of Molong (Bathurst 1 : 250,000 sheet SI 55–8, grid reference 171.904). The name was first applied as a reconnaissance term by Joplin and Culey

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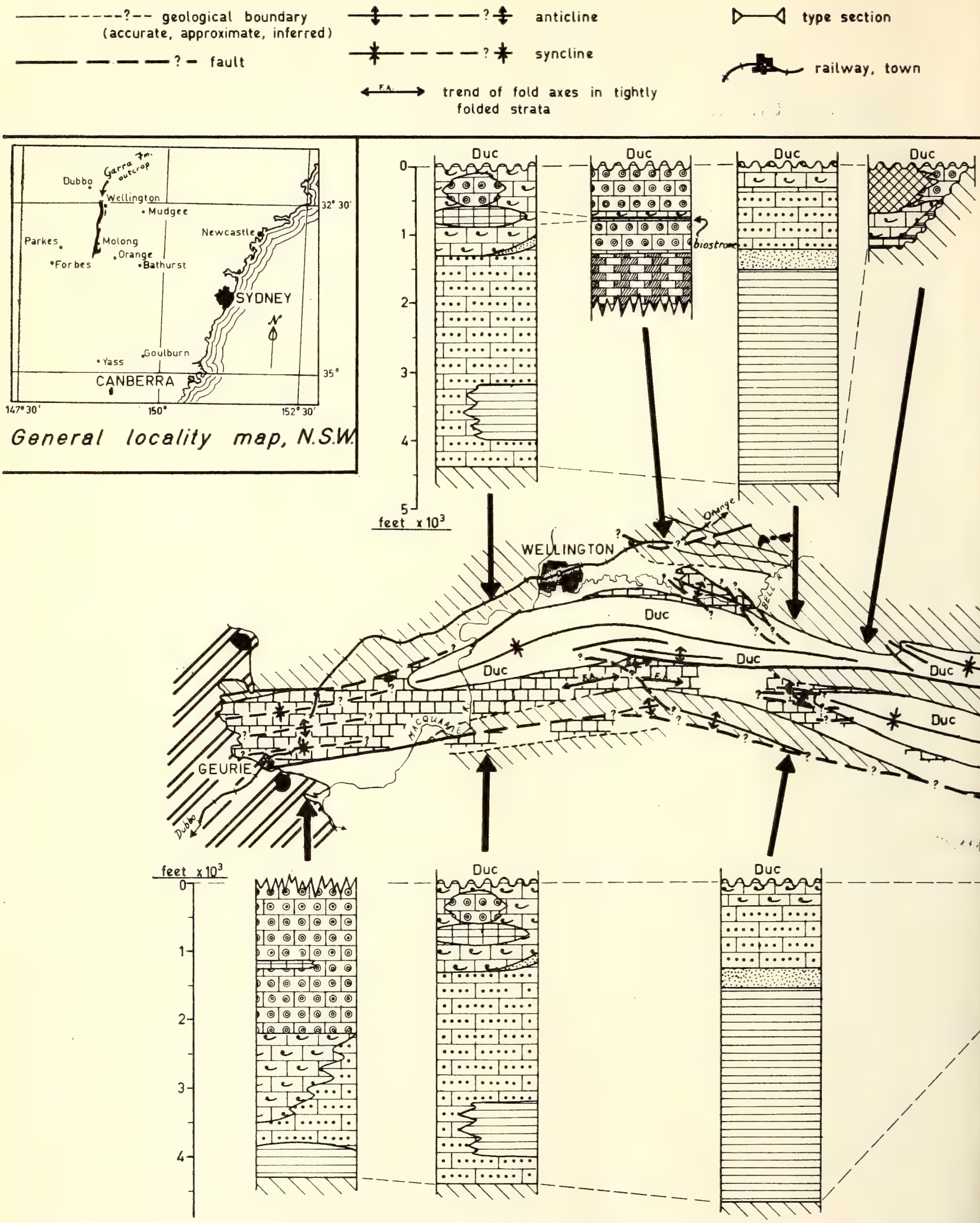
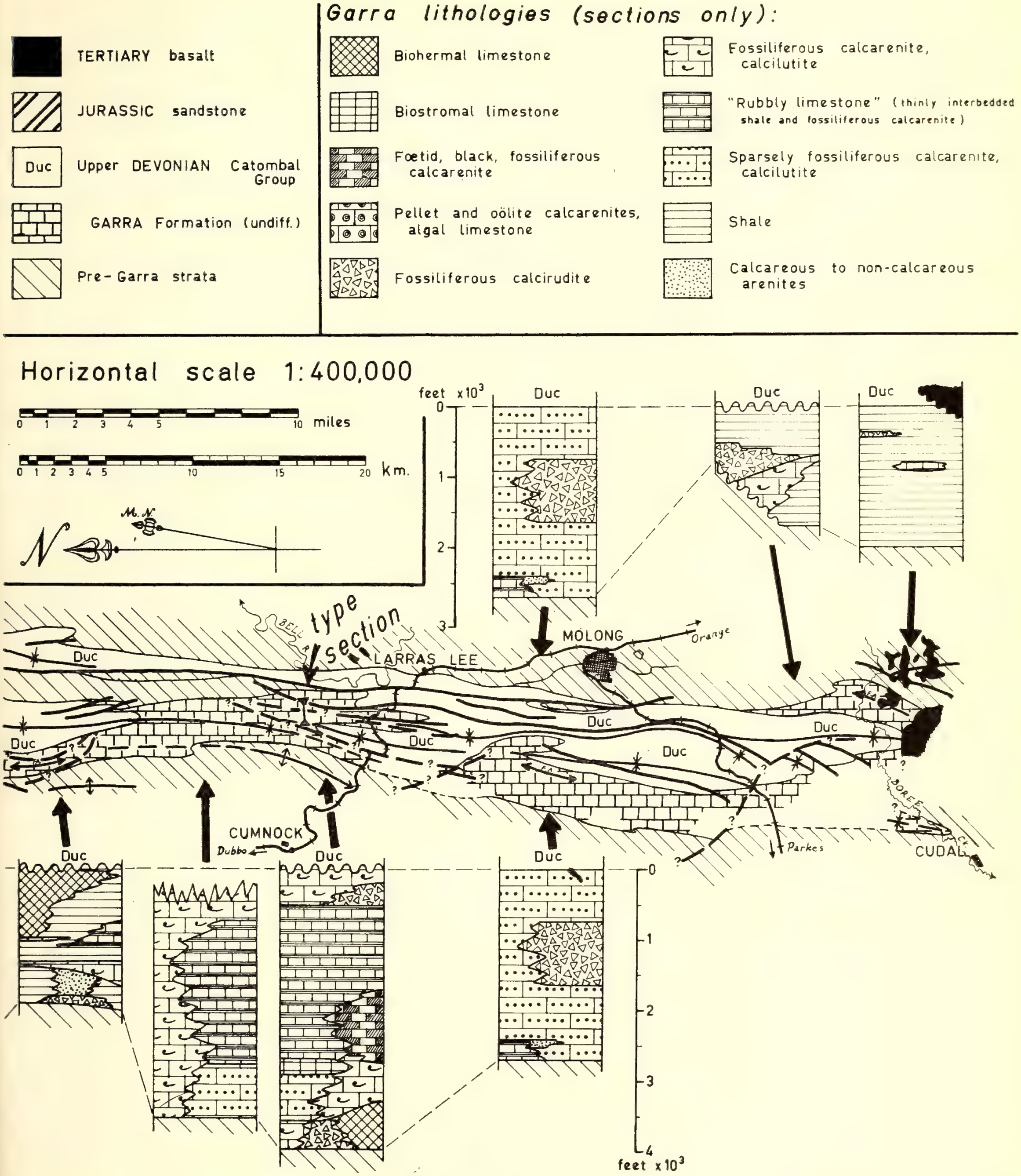


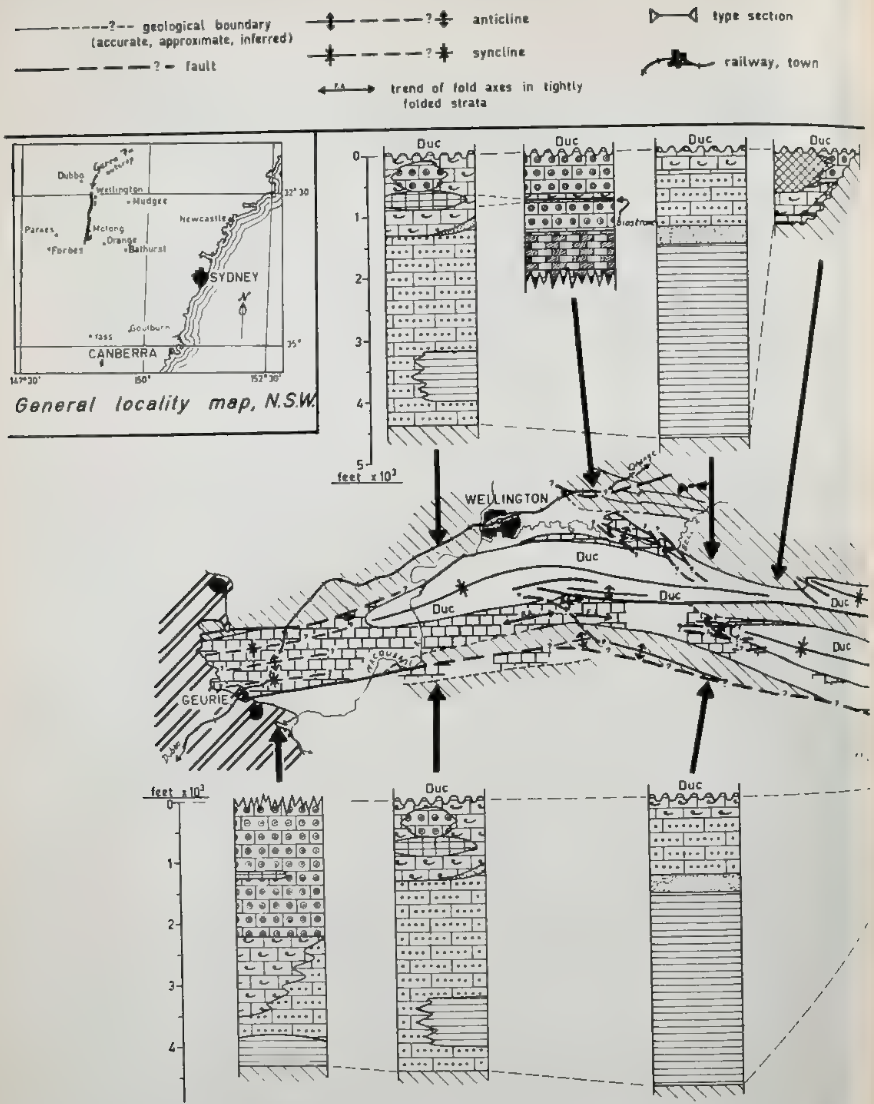
FIG. 1

Locality map (inset), geological map, and diagrammatic tentative stratigraphic columns of the Garra Formation. The general areas for which the columns have been constructed are indicated. Note that much of the small-scale folding of the limestones has of necessity been omitted.



TERTIARY basalt
JURASSIC sandstone
Duc Upper DEVONIAN Catombal Group
GARRA Formation (undiff.)
Pre-Garra strata
Garra lithologies (sections only):
Biohermal limestone
Biostromal limestone
Fœtid, black, fossiliferous calcarenite
Pellet and oölite calcarenites, algal limestone
Fossiliferous calcirudite
Fossiliferous calcarenite, calcilutite
"Rubbly limestone" (thinly interbedded shale and fossiliferous calcarenite)
Sparsely fossiliferous calcarenite, calcilutite
Shale
Calcareous to non-calcareous arenites
Horizontal scale 1:400,000
miles
km.
M.N.
N
feet x10³
type section
LARRAS LEE
MOLONG
Orange
BELL R.
Duc
CUMNOCK
Dubbo
Parkes
BOREE CK.
CUDAL

Fig. 1 (*cont.*)



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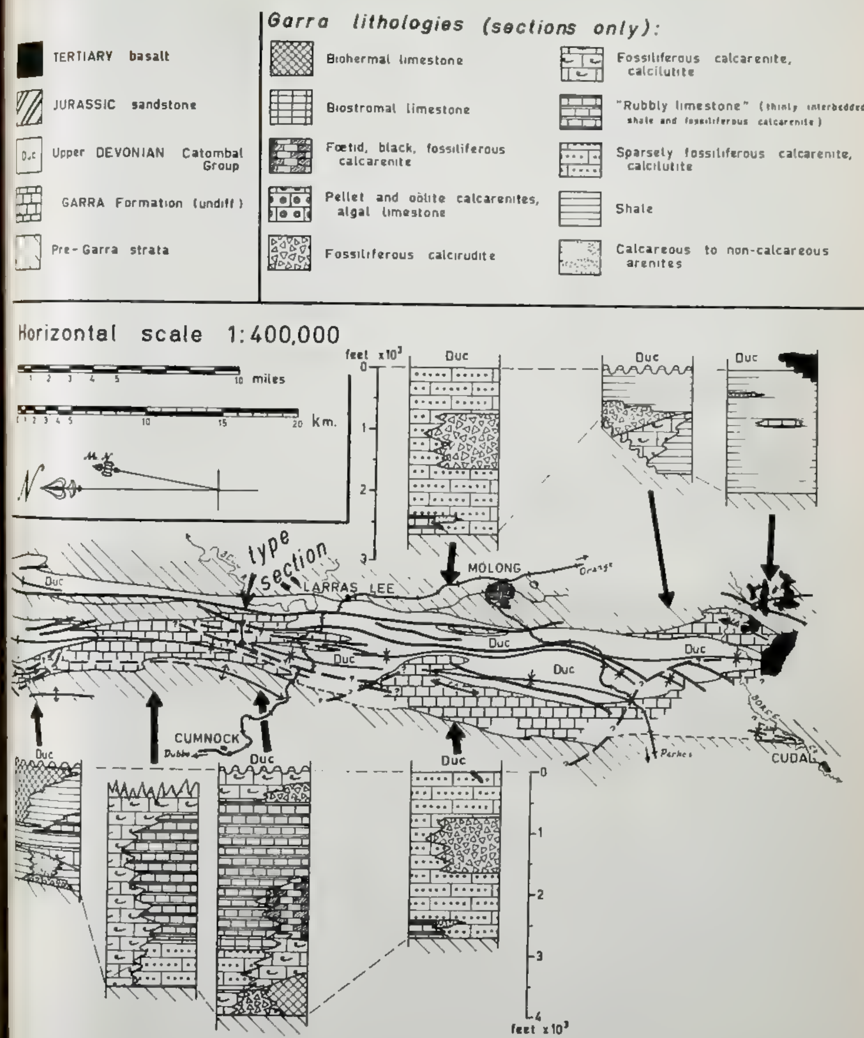

FIG. 1 (*cont.*)

(1938). The choice of name was unfortunate in so far as outcrops are very sparse in the vicinity of Garra, but the name has been widely used, and so is retained. Better outcrops, typical of the major lithologies of the formation, occur north of the region mapped by Joplin and Culey, for a distance of some 12 miles north from The Gap (west of Larras Lee).

Type section: In a complex reef suite such as is represented by the Garra Formation, certain reservations must be held when designating a type section. The danger is that later workers will try to apply too literally the "type" idea; for in the deposits of a reef environment, variation is so rapid and complex that any section will both include a large variety of lithologies, yet probably omit many more. Therefore it is most unlikely that any one section will be fully representative of the suite. Could the Garra Formation be divided into a large number of distinct, relatively uniform, and mappable units of small extent, then this difficulty could be resolved, but such division is apparently not possible. So it must be accepted that a "type" section, in the sense of a section showing the full lithological content of the formation, cannot be designated. A further, pragmatic, reason why this cannot be done is the unfortunate fact that there is no fully exposed section extending from base to top of the formation.

Probably the most nearly complete section, and therefore the one here designated as the formal "type section" (with the above reservations), is in a gully, a tributary to Spring Creek, about $2\frac{1}{2}$ miles north of The Gap (see Text-fig. 1). This section covers about a third of the formation, but shows neither base nor top. The outcrops start some 100 yds. east of the road, and extend eastward through portion 53, parish of Eurimbula.

The best exposures of the topmost beds of the Garra Formation are in the Wellington district, in two areas. The first is a complex biostromal layer cropping out south of the Macquarie River west of Wellington, in "Macquarie Park", por. 103, ph. Ponto. The second is a large area of massive limestone, with some biostromal layers, along the west bank of the Bell River, opposite the Wellington Caves Reserve and golf links (parish of Curra). On the basis of the close similarity of the contained faunas, the most extensive of the biostromes in the latter area is almost certainly the same horizon as that cropping out in "Macquarie Park".

Basal beds are exposed in a number of localities. Typical are the outcrops in Mountain Waterhole Creek (por. 25, ph. Curra, between Curra Creek and the Wellington-Cumnock road; Dubbo sheet SI 55–4, grid ref. 182.965). Others are: in Loombah Creek and the western part of Sawpit Gully (ph. Catombal; Dubbo sheet, grid ref. c. 176.941); and in por. 2, ph. Cudal (Bathurst sheet, grid ref. c. 171.887). At the last locality, there is a transition, over a thickness of some two feet, from tuffaceous sandstone belonging to the underlying formation, to a fossiliferous calcarenite at the base of Garra Formation biostromal limestone.

It is highly likely that the basal beds exposed at various localities over the length of the formation vary somewhat in age, although probably deposition nowhere ceased long enough for there to be significant erosion. This contrasts with the top of the formation, which is transected by an unconformity.

Lithologies: The Garra Formation consists essentially of interbedded and intertonguing clastic limestones, biostromal limestones, and bioherms. The clastic beds range from very coarse calcirudites, through calcarenites, to calcilutites, and from pure calcareous rocks to non-calcareous shales and siltstones; a few thin beds of calcareous tuffaceous sandstone occur near the base of the formation, and two lenses of quartzose sandstone near the top. There are also areas in which the limestones are massive beds of pellet calcarenites, oölites, and algal limestones—these are extensively developed north of the Macquarie River, and along both sides of the Bell River in the Wellington Caves region, both areas being at the northern end of the formation.

The predominant lithology is fossiliferous calcarenite to calcilutite. Thin beds of these are frequently interbedded with lesser quantities of non-calcareous shale, forming distinctive outcrops of "rubbly limestone".

Thickness: Because of the difficulties introduced by sporadic outcrop, together with complications from folding and extensive strike-faulting, it is possible to do no more than estimate the thickness of the formation. Moreover, available evidence strongly suggests that there is considerable variation over the 60 miles of outcrop; this of course is to be expected in a reef environment. Over the greater part of the formation, the thickness seems to be of the order of 3,000 to 4,000 feet. Some idea of the variation in estimated thickness is shown by the tentative and diagrammatic stratigraphic columns in Text-fig. 1.

FAUNA AND AGE: Hill (1942) recognized two distinct coral faunas, one probably Coblenzian at the base of the formation, and the other Couvinian at the top of the formation, in the Mickety Mulga region west of Wellington. The more detailed mapping, and much more extensive collecting, that could be done during the author's study have shown that this subdivision of the fauna is not tenable.

Until considerably more work is done on eastern Australian faunas, an accurate age cannot be assigned to the Garra fauna, but its closest associations appear to be with the faunas of the Murrumbidgee district, near Yass, N.S.W., the faunas of the Sulcor and Loomberah limestones of Tamworth, N.S.W., and the Buchan fauna of Victoria, all of which have been previously regarded as Couvinian, possibly ranging down into the Emsian. Pedder (1964) has suggested that some of these may be older, perhaps Siegenian. Dr. G. M. Philip (in litt.) has noted that " The ammonoid evidence for the Middle Devonian age of the Buchan sequence is not unequivocal, and is amenable to the interpretation of an Upper Lower Devonian age ". At present, it seems that the Garra Formation is either Emsian or early Couvinian, and most probably the former.

CONTIGUOUS FORMATIONS: The Garra Formation conformably overlies a sequence of acid to intermediate volcanic rocks and sediments, which were included by Joplin and Culey (1938, pp. 270–272) in their Manildra Beds. These and related strata are at present being studied by Mr. D. Maggs of the University of New South Wales, and Mr. N. Savage of the University of Sydney; their findings so far indicate a continuous succession from Lower Silurian strata into the Garra Formation.

Overlying the formation are the orthoquartzites at the base of the Catombal Group (see Conolly, 1963), considered to be of Late Devonian age. Joplin and Culey (1938, p. 275) considered the Catombal Group to overlie conformably the Garra Formation, but Basnett and Colditz (1946, p. 46) and later Joplin and others (1952, p. 86) proposed a broad regional unconformity. The author agrees with Dr. Conolly (1963, p. 74) that the relationship is structurally conformable in the north (there is probably a disconformity), and mildly unconformable near Molong (see Text-fig. 1). It is possible that near the Orange-Parkes highway in the south the relationship is again disconformable. See also Walker (1959, p. 45).

STRUCTURE: The overall pattern of folding and faulting which has affected both the Garra Formation and its adjacent formations has been summarized by Conolly (1963); it consists of large doubly-plunging folds, cut by numerous strike and oblique faults. The poorly competent calcareous shales and thinly-bedded limestones of the Garra Formation show a considerable amount of small-scale folding and crumpling.

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The Foundations of the Geological Survey of New South Wales

Ann Mozley
Adolph Basser Library, Australian Academy of Science, Canberra

Abstract—The background of events leading to the appointment of the first geological surveyor in New South Wales is traced with an account of the pioneering survey work carried out by Samuel Stutchbury and the Rev. W. B. Clarke which laid the foundations of geological survey in New South Wales.

Australia had been settled for over sixty years before the attention of the British Government was seriously called to the need for a government-sponsored geological survey in the eastern colonies. Adolarious Humphrey, it was true, had been appointed mineralogist to the Territories of New South Wales by the Home Government in 1803 and sailed with David Collins to plant a new settlement on the southern coast. But Humphrey gave little mineralogical service in New South Wales. When the settlement at Port Phillip foundered, he transferred with the party to Van Diemen's Land, and it was here that most of his geological investigation was made. No reports, however, commemorate his work and it was evidently with some relief that he resigned his lonely scientific post in 1812 and became a magistrate.[1]

Britain had established her Geological Survey in 1835, Canada in 1842, while the small Colony of Newfoundland enjoyed the services of a geological surveyor from 1839–41. In America by the same period, geological surveys had been independently launched in at least fifteen of her States.[2] In Australia, however, the climate of colonial opinion was unfavourable to expenditure on science. " Zoology, Mineralogy, and Astronomy, and Botany, and other sciences " declared one Sydney newspaper in 1833 " are all very good things, but we have no great opinion of an infantile people being taxed to promote them. An infant Colony cannot afford to become scientific for the benefit of mankind."[3] As one eminent citizen pertinently summed up the philistine spirit of the time : " The only animals whose natural history it is deemed of consequence to investigate in New South Wales are the sheep and the bull ", and the only branch of study that has hitherto engrossed the pursuit of all classes is, " *how to make the most of it* "[4]

By the decade of the forties, however, the zeal of a handful of scientific men had revealed encouraging evidence of the Colony's mineral wealth. Paul Edmund Strzelecki, visiting Polish explorer, in 1839 found particles of gold in the Vale of Clydd, while the Cambridge trained geologist, the Rev. W. B. Clarke, searching with his hammer among the granite and the quartziferous slates of the Great Dividing Range, discovered traces of the metal near Hartley in 1841. Clarke communicated the news to his friends and began enthusiastic prediction of the Colony's potential wealth. He drew the attention of the Legislature to his finds,[5] and in April 1844 called upon the Governor, Sir George Gipps, with some gold speckled specimens of rock found a month earlier on the banks of the River Page. His visit, the clergyman reported later, caused the agitated Governor of a convict settlement to exclaim, " Put it away Mr. Clarke or we shall all have our throats cut "[6] which schoolboys have relished for over a hundred years.

But Clarke did not put his gold away nor desist in his predictions of wealth, and evidence suggests that it was less fear than apathy that held back an official mineralogical search. For Clarke's opinion coloured the thinking of another active cleric, the Rev. Dr. John Dunmore Lang, who moved in the Legislative Council in August 1845 that a sum be placed on the estimates for the commencement of a geological survey in New South Wales. The motion was rejected by fifteen votes to ten, eight who voted against the measure, Lang noted, being paid officials or crown nominees. " Had this useless lumber not interfered to clog the wheels of the legislature ", Lang reflected acidly, " this important measure should have been carried by a majority of three. As a consequence gold might have been discovered in New South Wales before it was found in California."[7]

It was Strzelecki, in his pioneering work on Australian physiography, who first directed British attention to the importance of a

geological survey of New South Wales and Van Dieman's Land. Although his own strange verdict, after travelling some seven thousand miles on foot and horseback, claimed that " the scarcity of minerals was such as might have discouraged the most ardent and persevering mineralogist who had ever devoted himself to science ",[8] he pressed the needs for a government financed survey conducted on liberal principles to hasten the pastoral and agricultural destinies of the eastern colonies, in which he profoundly believed, and to throw scientific light on the geological analogies of Australia with the rest of the world.

The Polish " Count ", with influential friends in London, was well placed to promote such a plan, and in June 1845 he wrote encouragingly to his Sydney friend, Captain P. P. King:

> There is great probability that I should be able to secure to the two Colonies a Government Establishment called the Economic Geology, which will be a branch of the office of the Ordnance Geological Survey of Great Britain under the direction of Sir Henry de la Beche—with a Geologist and a Chemist and through which a thorough Geological Survey of the two Colonies will be made and such questions of chemistry and mineralogy solved, as the developments of mining and agriculture may require.[9]

In England Roderick Murchison, active and illustrious geologist, interested himself in Strzelecki's work, and the resemblances he discerned between the explorer's specimens brought from the Great Dividing Range and those of the gold-bearing Ural chain, from which he had lately returned, led him to make positive predictions of Australia's auriferous wealth,[10] and, as news of gold began to trickle back to London,[11] to urge upon the Secretary of State the desirability of instituting a mineralogical search.[12]

While the British Government remained unresponsive to these pressures, the spread of speculative mining in the Colonies and the warning of experienced scientists of the dangers and waste of unregulated mining activity in Australia directed a more immediate interest to the rocks that lay beneath the pastoral soil. " Thousands of pounds will probably be thrown away by misdirected efforts " counselled the visiting geologist J. Beete Jukes, " which a mere outline survey of the districts, conducted on sound principles would direct into proper channels " and from his own experience as former geological surveyor of Newfoundland, he urged that " positive and direct benefits could hardly fail to result from a good survey, not only to the mining interests, but also to the agricultural, the engineering, and all other operations connected with the soil and with the rocks below it ".[13]

By the beginning of 1849, the Colonial Government was ready to proceed on such advice. Subsequent interpretations of the history of gold in Australia were to attribute to the Californian discoveries an undue influence in shaping Government policy in New South Wales. The pressures, however, came from nearer home. The successful development of the copper mines in South Australia; the appearance of the ore in New South Wales at Carcoar, Molong and Bathurst; the discovery of iron ore at Berrima and of copper and lead at Yass, and the many unconfirmed reports that gold had been found in several places across the mountains prompted the Government to act and on 1 March 1849, the Governor, Sir Charles FitzRoy, addressed a despatch to the Secretary of State for the Colonies requesting the appointment of a Geological Surveyor to New South Wales.

> I am desirous of bringing under your Lordship's notice [wrote FitzRoy] the expediency of causing a Mineral and Geological Survey to be made of the Colony in order to determine the mineral resources which it may possess . . . I have thought it necessary to trouble your Lordship in order to show the probability that if the country were examined by a competent Geologist who would be at liberty to devote his time exclusively to this object, valuable metalliferous ores would be discovered, which would not fail to add greatly to the resources of the Colony, extensively to benefit the Land Fund, and thus to open out a new field for British Emigration . . . The information thus obtained would, there is little doubt, he found highly valuable both in an economic and scientific point of view.[14]

Samuel Stutchbury

The task of selecting a well-qualified geologist was entrusted to the Director of the British Geological Survey, Sir Henry de la Beche. He offered it to the experienced J. B. Jukes, then a member of his own Survey. " I hesitated a little before I declined it ", Jukes confided to his friend W. B. Clarke, " I should have enjoyed

it much—but I have had some experience of colonial appointments, and have little faith in their permanency."[15] H. W. Bristow, another member of the British Survey, was next approached, but resigned for family reasons, shortly before he was due to sail for the Colony. A harried Director engaged Samuel Stutchbury, Curator of the British Philosophical Institute, in May 1850 and committed him without delay to a free passage to Australia. A man, " well instructed in our mode of work on the Geological Survey of Great Britain ", de la Beche assured the Governor, Stutchbury had " great experience as a Coal Viewer, and is perfectly acquainted not only with Mineralogy as a science, but also practically with the mode of occurrence of the ores of the useful metals."[16]

Samuel Stutchbury, first Government Geological Surveyor to New South Wales.

By courtesy of the Mitchell Library.

Expectations of the new geological surveyor were less sanguine in New South Wales. " It is understood ", a *Sydney Morning Herald* editorial announced on November 4th, a fortnight before Stutchbury landed, " that a *naturalist* of some eminence, Curator of a Museum in England, is to come out ; but it is very unlikely that that gentleman will feel himself ready to undertake a *geological* survey,

though highly useful as an observer and collector."

The writer was the Rev. W. B. Clarke, scientific doyen of the Colony and since 1839 " cock of the geological walk ". After many years of private geologizing in the Colony, Clarke hoped to publish his researches with government aid ; he had not been conspicuous among those who had pressed for an official geological survey of New South Wales,[17] and he fretted keenly at the choice of one whose qualification for this arduous undertaking appeared to be long service in the sanctuary of a Bristol museum and the publication of a paper on the growth of young corals of the genus Fungia. His critical comment, under the shadow of anonymity, left little doubt among the knowing, of his own aspiration to the post. " There might perhaps have been found in the colony ", he concluded pointedly, " the means of carrying out the desires of the Government without going further and faring worse ; but is is certain that, for some time to come, the colony must be content to wait for anything more official than the zeal and intelligence that volunteer services may supply."

Samuel Stutchbury, a quiet and conventional Englishman about whom little is known before his acceptance of the geological surveyorship carried him to an unenthusiastic reception in New South Wales, arrived in Sydney on 16th November 1850. His appointment, he found, was not regarded as a permanent one, though it was considered not unlikely " that it may extend over a period of several years ". His salary was £600 a year. After four months at sea, he was eager to take up his task, proceeding as his letter of appointment urged to districts where metalliferous ores had been found, and advising the Government in quarterly reports of the range of the mineral areas. The Governor's absence at Bathurst, however, obliged Stutchbury to wait and it was not until 18th February 1851 that he set off with a dray and two servants to begin his methodical survey of the Colony at the Bathurst copper mines. It was just three weeks before Edward Hargraves, newly returned from California, was to ride up the same path to the mountains ; and only a few weeks more before that talented adventurer was to dazzle the Colonial Secretary with his showman's confidence and his tiny particles of gold.

From his camp at the Bathurst Cornish settlement Stutchbury noted in his diary on 3rd March " There can be no doubt that the whole of these ranges are highly metalliferous ".[18] It was indeed, as he advised the Colonial Secretary in April, what in his own part of the west of England would be called " a kindly sort of country ".[19] From the Government viewpoint, however, such information was already too late. Hargraves had cradled the rich alluvial gold of Lewis Ponds and, presenting the Government with an ultimatum that April, had destroyed all prospect of orderly mining development in New South Wales. Just how kindly the ranges had proved, Stutchbury learnt from a newspaper in Carcoar on 4th May, and six days later he received directions from the Colonial Secretary that the successful prospector was on his way to consult him in reference to the discovery.

From that day, the geological surveyor's role became a secondary one. He met Hargraves at Coombing on 10th May and saw his four ounces of gold. Four days later they met again to ride to Lewis Ponds, where several parties were already digging for gold. Stutchbury reported to the waiting Government the existence of grain gold, but it was not until his fuller report from Ophir on 19th May that " gold had been found in considerable quantity . . . I have found it far above the high flood line of the Creek in various places, proving it to originate in the mountains, and washed down by the rain "[20] that the Administration stirred and, frustrated in their hopes for a regulated mineral survey, made public the news that would release the flood of diggers across the Dividing Range.

W. B. Clarke

In this unexpected emergency in the affairs of the Geological Survey, the chief adviser to the Government was not the accredited surveyor, Mr. Stutchbury, but the Colony's geological savant, the Rev. W. B. Clarke. " We were in frequent communications with him ", Deas Thomson recalled some years later, " for he was considered a great authority, and he was very kind in giving information to the Government that was useful to it ".[21] Clarke offered his services voluntarily to the Government in May and from his own fieldwork and extended study listed the areas in the north and south of the Colony where gold might be found. It was Clarke who drafted the revised instructions sent to Samuel Stutchbury and Sir Thomas Mitchell, the Surveyor-General (recruited to conduct a survey from Canobolas to the north) on 21st May defining the geological data to be sought in connection with gold, and who appeared like an *eminence gris* in the Colonial

Secretary's office early in June when Hargraves himself was called to receive instructions as Commissioner of Crown Lands, and wrote down at Deas Thomson's request the scientific sign-posts to the location of gold.[22] In the event, Hargraves never again discovered fresh sources of gold, though he remained in the employment of the Government for several years.

Rev. W. B. Clarke, *c.* 1851.

By courtesy of the Basser Library.

Clarke's opportunity to serve the Government and to put his own theories to the test of fieldwork came later in the year. In July he discussed with the Governor and the Colonial Secretary a plan to extend the gold survey systematically throughout New South Wales. It was the Government's intention to sponsor a joint survey conducted by the two geologists Clarke and Stutchbury reporting to a co-ordinating board. But to this proposition, the pioneering geologist flatly declined to accede. " When you consider ", he wrote Deas Thomson on 7th July 1851,

> that I have been at work unassisted in any way for 12 years, that I have nearly finished a survey of the whole country, and that it is my wish to complete it by myself, you will see at once how completely opposed it will be to my design and desire to be bound and shackled by those who will not keep pace with me, and whom I must either work for, or yield to, often perhaps against my own conclusions . . . With an able practical geologist who has really acquired his experience in the field I should be glad to work in company, but

> as this cannot be . . . I can only in common justice to myself and what is expected of me, offer my services unfettered by connection with others.

With a Government not entirely satisfied with its own geological surveyor, Clarke's point prevailed, and on 11th July Stutchbury was advised to " proceed with the general Geological Survey " according to instructions received before the gold discoveries had interrupted his work. The more pressing matter of the gold survey was entrusted to Clarke alone and at the beginning of September this enterprising clergyman was added to the Colonial Estimates as a geological surveyor at a salary (fixed to remunerate him for the loss of his clerical stipend) of £300 a year. Eleven days later, he rode off from his rectory at Saint Thomas', North Sydney, with a cart and two servants assigned by the Government and with cradle, picks and prospecting pans, to begin his survey in the south. With him he carried his Bishop's blessing, and a licence in his pocket to minister God's word and His eternal riches as he searched the earth for the evidence of gold.

W. B. Clarke was engaged for nine months on a survey of the southern goldfield which took him from Marulan south-west to Tumut and Kosciusko, south to the sources of the Snowy and the Bendoc Rivers, east to Cape Howe and Pambula, and inland by way of Monaro to complete his examination of the country where he began, " upon a ' field of gold ' ".[23] His eighteen reports written in camp at the end of an arduous day present a strikingly co-ordinated picture of the physiography and structure of this broken region of uplift, igneous intrusion and trappean[24] overflow ; and his generalizations on its stratigraphy have stood the test of later detailed research.

From his starting point on the Shoalhaven, Clarke carried his earlier identification of the carboniferous formation of the Colony to its outliers between Marulan and Goulburn, where it passed into the older sedimentary rocks and made positive identification of the palaeozoic basis of southern New South Wales. At Molonglo and the Limestone Plains, he observed the Silurian formation " distinctly marked by alternations of beds . . . and by abundance of fossils that leave no doubt as to its geological epoch ",[25] and he traced the same alternations and succession in the rocks to Queanbeyan, along the Murrumbidgee, to the Colony's southern heights. Despite a comparative absence of fossil evidence, his determination of the Devonian strata was equally precise ; fossils discovered in the ranges between Yass and the Murrumbidgee he assigned to this epoch, and he tentatively placed the grits and sandstone of Pambula in the county of Auckland in the Devonian system.[26]

In 1851–2, therefore, his able stratigraphic identifications in the southern districts were sufficiently firm to dispel the suspicion long entertained in geological circles in England that Australia was of recent geological age.

> Although the information obtained may not be sufficient to arrange the Australian succession in intimate analogy with the succession in Europe, [Clarke wrote from Eden in March 1852] I nevertheless desire to record in this place my conviction, that the general order of succession appears to be so far certain, that further enquiries will be conducted with less difficulty than heretofore . . . The existence of the fossils of the Silurian system, and, as I believe, also the existence . . . of a formation analogous to, if not identical with, some portion of the Devonian system of Europe, have been made out . . . These facts and inferences are important, as they demonstrate unequivocally that the greater portion of New South Wales is occupied by Palaeozoic formations of the older class, and that, therefore, it is one of the oldest countries on the face of the globe.[27]

Clarke was also to note down on this expedition the first evidence of glacial phenomena in Australia at Kosciusko ; and less than a decade after Agassiz's controversial theory of glacial action had been adopted by European scientists, he observed " Probably in earlier times glaciers did form ; for I saw more than one unmistakable *bloc perché*, a mass resting on upturned strata ".[28]

Against this background of geological enquiry he reported to the Government no less than ninety-five productive areas of gold and ended his survey with the confident assertion that gold was distributed though in variable quantities over a region of some 16,000 square miles south of the parallel of Marulan, excepting only the three eastern counties of St. Vincent, Dampier and Auckland. Lead, copper and iron, he believed, would also be found in the county of Murray.

In his search for geological constants in the location of gold, Clarke demonstrated that the metal was to be found in southern New South Wales in certain granites, notably hornblende[29] ; in the older sedimentary rocks where quartz was common and where river channels dissected

the meridional line of strike[30]; in regions of igneous and metamorphic activity, and, importantly, in connection with trap.[31] His evidence, collected over large tracts of auriferous country, attested also to the astonishing variableness of gold in matrix which he had found in quartz veins, ironstone, sandstone and conglomerates of different epochs. The whole history of the origin of gold the geologist concluded " rested on a more perfect understanding of the natural history of trappean eruptions "[32] and, at a time when few English geologists had interested themselves in the theory of ore deposits,[33] Clarke's detailed and careful findings from the Australian goldfields were an important contribution to this enquiry.

The pioneering geologist also brought evidence from his own fieldwork to bear on Roderick Murchison's keenly held theory that altitude was an essential corollary to quantity in gold. Clarke had sought the metal in vain in the summit of Kosciusko, finding it rather in the granite at a much lower level in the range he named Muniong, and, in general, most prolifically at a level of 2000 feet; and ardent controversialist as he was on this subject, he wrote jubilantly to the Colonial Secretary: " I am glad, if, for no other reason, I have been able to carry a cradle, prospecting pan, pick and shovel, over some of the highest peaks of the continent, and up and down the faces of generally precipitous mountains, the planes of the slope of which are . . . perfect escarpments."[34]

Clarke's penetrating reports of the southern goldfields, blending observation with theory and seasoned with a practical good sense that was to make them invaluable guides to prospectors when he published them in book form in 1860, were printed as they came to hand, as parliamentary papers, and won high praise from the Government. The Colonial Secretary wrote while Clarke was still in the field to convey the Governor General's satisfaction with the " able and scientific manner " in which Clarke had carried out so large and complex a survey, and to express the hope that he might be spared from his spiritual duties to carry the investigation to other parts.[35]

Samuel Stutchbury, meanwhile, had resumed his survey from Bathurst to the north. After his first communications to the Government on the gold discovery, " meagre and unsatisfactory and particularly unscientific and unbusinesslike " a critical administration had described them,[36] he had settled into his stride and his ten reports on the present State of New South Wales gain in competence and confidence as he moved northward. In July, he notified the discovery of copper at Canobolas and of rich iron ore at Coombing Park, which he considered, " if all things also were compatible . . . is sufficient to supply another Sheffield for ages to come ".[37] His 6th Report describes the coal beds at Dubbo; his 8th the coal fields of Talbragar, and he was to carry these detailed examinations of the carbonaceous formations to the Darling Downs.

From the outset of his appointment, however, Stutchbury suffered from a very real sense of isolation in his work, and his personal diary, preserved in the Mitchell Library, bears witness to the loneliness of his private struggle and of his determination to fulfil the terms of the undertaking to which he was pledged. " I may take this opportunity " he wrote down after some eighteen months in the Colony, "of recording my feelings of disappointment and pain at the general treatment I have met with from the Colonial Government from the moment of entering upon the duties of my survey until the present time. Arrived, a stranger in this country, unacquainted with the peculiar requisites for a lengthened sojourn in the Australian ' bush '; a never ending journey, not alone from township to township, but not infrequently beyond the boundaries of settlement and civilization, I was left almost entirely to my own resources, and did not receive the aid and assistance which I think I was entitled to look for and expect."[38] Stutchbury criticized in particular the lack of assistance for carrying out his task, and he notes that from his own pocket he paid the wages of an extra servant and a native boy so that no reflection should fall on those friends in England who had helped him to the post.[39]

It was a serious indictment of the Government, yet the blame was not all on one side. Stutchbury's limited experience of fieldwork and his ignorance of the rough conditions of life in Australia left him particularly exposed, and his plight was not eased by the contrast which Clarke's single-handed and enterprising efforts afforded in the south. " You could not have a better foil ", wrote Captain P. P. King, charged with the task of editing the reports of the geological surveyors, to Clarke in February 1852; and this view of Stutchbury was widely shared. Overshadowed by the pioneering geologist, and cut off throughout his period of service from personal contact with the administrators, Stutchbury, despite the competence of much of his work, never succeeded in winning the confidence of the Government.

His few communications with Clarke moreover reveal the distrust and rivalry which lay, not surprisingly, close to the surface in the relationship of the two geological surveyors in New South Wales. After three months in his parish Clarke, in September 1852, was again in the field, converging towards Stutchbury in the north. " I thought I was working my way up (geologically) towards the Hunter River beds ", Stutchbury wrote him tartly in December,[40] " and I intended going to Mt. Wingen, and then crossing to New England on the route which I now find you have taken up." He was critical of specimens Clarke had sent him, which he found " so small and indistinct as to be scarcely distinguishable ", a criticism, in fact, often levelled at the pioneering geologist. The clergyman, for his part, kindly in all matters where scientific reputations were not involved, had sent Stutchbury a prescription for an ailment that had long hung on. " I have too much faith in my own knowledge of medicines ", Stutchbury replied somewhat darkly to this overture, " to take any remedy without being acquainted with its component parts ! " Six weeks later, however, he acknowledged its success. Yet little friendliness prevailed. " If it is not impertinent ", he enquired of Clarke in February 1853, " I should like to know the route you have made and your intended course." Clarke's answers, unfortunately, have not been preserved.

Clarke spent nine months in northern New South Wales and submitted ten reports to the Government. He examined the diggings at Hanging Rock and the Bingara gold fields, tracing the gold drifts over considerable areas of New England. He pronounced it " local gold ", suggesting that its first dispersion was brought about by the waters of the ocean during one of the oscillations in the vertical ascents and descents of the cordillera. " It will be seen at a glance ", he wrote accordingly from Tamworth in December 1852, " that he who would limit his idea of the wealth of our hills and valleys to what has been produced from such scratches and furrows as our Golddiggers have hitherto contented themselves with making, or who would dogmatically and presumptuously say that the Gold fields are limited to what can be scanned with the eye alone, has yet to learn very much . . . The more I see of the backbone of this Continent, the more I am impressed with the high probability of the extension of the Gold fields far beyond the present limits of search."[41]

In November 1852, he reported the existence of oxide of tin with tourmaline near Dundee and in Paradise Creek, a tributary of the McIntyre (he had recorded it earlier in the southern Alps), and noted the probability that the ore would be found plentifully distributed in the alluvia of other tracts, " as I have found it amidst the spinelle, rubies, oriental emeralds, sapphires and other gems of the detritus from granite[42] " ; anticipations abundantly realized when the rush to the New England tin mines broke in 1872.

In his most elaborate and thoughtful report from the northern districts, written from the Severn River in May 1853, Clarke set down some pioneering observations on the structure and origins of the highlands of New England on which the first detailed surveys by Wilkinson, David and Andrews were laid. He found the solid nucleus of New England, the Upper Clarence districts, and part of Gwydir and Liverpool Plain was granite of some kind, some " of the oldest formation ", while " bursting through both granite and porphyry and overflowing them, basalts, amygdaloids, and small proportion of greenstone, form a third kind of igneous rock ". These formed the culminating point of the Dividing Range on the Ben Lomond Range, breaking out along the spurs in various places on the western falls. The period of this overflow, Clarke attributed to " posterior to the carboniferous formation ".[43]

In his Northern reports, Clarke also followed the beds of the carbonaceous formations of the Colony from the coastal deposits of the Hunter, the basins of the Karau, Gloucester, Clarence and Richmond Rivers to the western coalfields and thence to Darling Downs and Moreton Bay ; assigning them all, at this time, to a palaeozoic age. His tenth report took him to southern Queensland, where he described the basin of the Condamine, the Darling Downs and Moreton Bay, exploratory work to which Jack and Etheridge paid tribute in their classic work on the geology and palaeontology of Queensland.[44]

Clarke completed his survey in June 1853, and returned to his parish in Sydney. " My labours ", he replied to the thanks of a grateful Government, " were nothing compared with what geology must do hereafter." Yet he had, geologically, cut a swathe through the entire eastern sector of New South Wales and offered explicit evidence of the varied metal and coal resources of the Colony.

Samuel Stutchbury, following Clarke into Queensland in October 1853, was to carry the

exploratory reconnaissance northwards, and, in his last two years in Australia, to set down the pioneering foundations of geological survey in Queensland (separated from New South Wales in 1859).

Writing of Stutchbury's contribution a century later, Professor W. H. Bryan nominates the surveyor's twelfth report from South Brisbane as the most " significant and interesting " on that State. In it, Bryan recounts,[45] Stutchbury described that are now known as the Capalaba Conglomerates, reported on the working of the coal measures near Mogill ; noted the limestones and Ipswich tracing them south for some eleven miles ; observed the evidence of recent uplift on the shores of Peel Island and named several of the recent corals so exposed. Moving northwards, he was to determine that a basal series of Silurian or older schists and slates was followed in geological succession by a series of fossiliferous limestones of Devonian age, and that these were succeeded by the coal measures, which, like Clarke, he assigned to the Carboniferous age.

Stutchbury's sixteenth and last report was written from Port Curtis on 20th November 1855, and submitting it, this reticent field geologist sums up something of his own sustained contribution to the geology of both New South Wales and Queensland. " If the maps accompanying my reports are put together ", he advised the Colonial Secretary, " it will be found that the area coloured occupies an extent from south to north exceeding eight hundred and fifty miles, with an east to west average breadth of thirty eight miles, thus making a total over 32,000 square miles by traverse work ; and I have much confidence it will be found closely approximating to the truth."[46]

Eleven days later, on 1st December 1855, Stutchbury was on a ship for England. No newspaper noticed his departure nor marked his five years of uninterrupted field work in the Colony ; and he readily became one of the forgotten men of Australian science. It was, however, the once critical Clarke who paid public tribute to Stutchbury after his death, when he gave evidence before a Select Committee in 1861. " Mr. Stutchbury has done his part for the neighbouring Colony of Queensland ", he then conceded, " as has Mr. Selwyn for the Colony of Victoria, and myself for New South Wales."[47]

Samuel Stutchbury's resignation brought to an end the official geological survey of New South Wales. The new Governor-General, Sir William Denison, an enlightened friend to science, had private hopes of promoting " a proper survey of the Colony " into which all available knowledge of the country should be poured ; " yet how difficult it is ", he confided to Sir Roderick Murchison in 1855 while Stutchbury was still in the field, " to persuade either individuals or governments, that it is both cheaper and better to do a thing well at once, than to act upon the principle that everything is good enough for the infancy and early life of the colony ".[48]

His words were curiously prophetic. Clarke's reports, together with Stutchbury's, were shelved by the Administration, and his determinations on the Colony's mineral wealth exerted no real influence on the mining policy of the Government. Indeed, as one angry miner protested publicly in 1861, " The Government have not, . . . and never had, a mining policy. They have been actuated throughout by a blind empiricism, and a thriftless expediency. It is seen alike in their treatment of the geologist (the Rev. W. B. Clarke), and in their shelving of his reports, and in their utter ignorance of the present wants of the mining population."[49]

It was not until 1873, seventeen years after Stutchbury's departure from the Colony, that the incontestable evidence of the Colony's mineral resources with the rush to the New England tin mines at Tingha, Inverell and Glen Innes, forced the Government to act and a Department of Mines was established that year. In 1874 C. S. Wilkinson, a former member of Selwyn's team on the Victorian Geological Survey, was nominated geological surveyor and, the following year, was placed in charge of a separate branch of the Survey Branch of the Mines Department.

In the long intervening years, however, it was the clergyman geologist William Branwhite Clarke who, declining the appointments of geological surveyor in Queensland, Tasmania and New Zealand, continued from his own private researches and at his own expense to advance the knowledge of the Colony's stratigraphy and palaeontology. In this period Clarke, in effect, filled the place of an official geological survey, conducting a correspondence with scientists and prospectors that might well have proved daunting to a government department ; assembling collections of specimens from all parts of Australia ; filling the cabinets of the Cambridge Woodwardian Museum, the Geological Society of London and the Australian Museum ; and acting as a source of consultation and exchange for the growing regiment of geological surveyors in the other Colonies. Clarke's major work *Remarks on the Sedimentary*

Formations of New South Wales reached its fourth edition in 1878, the year the pioneering geologist died, and two years later the accumulated details of his long and voluntary service to geology in the Colony formed the basis of the first geological map of New South Wales issued by the Mines Department. On these pioneering foundations, the systematic work of the permanent Geological Survey of New South Wales has been soundly laid.

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[11] At least two experienced prospectors in New South Wales, William Smith and Thomas Chapman, sent gold samples to Murchison during 1847 and 1848.

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[15] 20 Feb. 1850. W. B. Clarke Papers, Mitchell Library.

[16] 26 April 1850. Papers Rel. Geological Survey, op. cit., Enclos. 3 in No. 3.

* Acknowledgement is made to the Trustees of the Mitchell Library, Public Library of New South Wales, for permission to quote from the manuscript papers in their keeping.

[17] Professor Tate in his valuable survey "A Century of Geological Progress", *ANZAAS*, 1893, V, attributes a substantial influence to Clarke in establishing the survey in N.S.W., and this view has been perpetuated by other writers. The evidence of Clarke's own papers and press cuttings, however, does not support it.

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Radioactive Laterites in the National Park Area

I. A. Mumme

Introduction

During the last two years, the writer has been conducting a programme of measurement of normal gamma radiation intensities from various geological units exposed in the Sydney Basin.

These determinations were made along several hundreds of miles of traverses with an aerial scintillometer set up in a vehicle.

While conducting measurements of gamma-ray activity in the National Park area, the nodular lateritic masses covering the Hawkesbury sandstone were found to be weakly radioactive.

Gamma-ray spectrometry measurements showed that the radioactivity was mainly due to thorium series with a small contribution from radium C.

Purpose of the Gamma-ray Measurements

The purpose of this survey was twofold, namely

(1) to determine the actual levels of radioactivity occurring in the general Sydney area, and

(2) to determine whether or not it was possible to discriminate between the characteristic levels of radioactivity associated with the different geological formations.

Type of Instrument Used

The scintillation counter used was built by Canadian Atomic Energy Pty. Ltd., and included two $3'' \times 4''$ sodium iodide gamma-ray detectors and associated electrical circuits, and indicators. The detecting elements of sodium iodide (activated by thallium) scintillate under irradiation by gamma-rays.

This equipment is quite portable and because of its high sensitivity and short response time measurements could be carried out at a reasonable speed.

A conventional vibrator type power unit was used to provide the necessary 115 volts A.C. for the instrument from a 12 volt D.C. battery system.

A recorder was used to record the variations in radioactivity as measured by the counting ratemeter during the traversing.

Calibration

The measurements of gamma-ray intensity were expressed in absolute units using a radium standard, and applying the equation

$$\text{Dose rate (in milliroentgens/hour)} = \frac{0 \cdot 84 \times mc}{d^2}$$

where mc = the source strength in millicuries, and d = the distance in metres.

Corrections for Cosmic Rays

As it was necessary to subtract the effect of the cosmic rays to determine the intensities of the gamma-radiation from the various types of rock, reasonably accurate determinations of the effect of the cosmic rays had to be made. This was done by reading the instrument in a boat in Botany Bay at a distance of over a mile from the shore.

Interpretation of Radioactivity Records

While interpreting the radioactivity records and computing the levels of radioactivity for the various geological units traversed, anomalous readings were located which were significantly larger than the normal radiation from the Hawkesbury sandstone formation.

The radioactivity was found to be associated with nodular laterite capping over large areas of the Hawkesbury sandstone in the National Park area.

The results of one radiometric traverse from Heathcote to Waterfall across one small isolated patch of laterite in the vicinity of Sebastopol trig. station (locality map—Fig. 1) is presented in Figure 2.

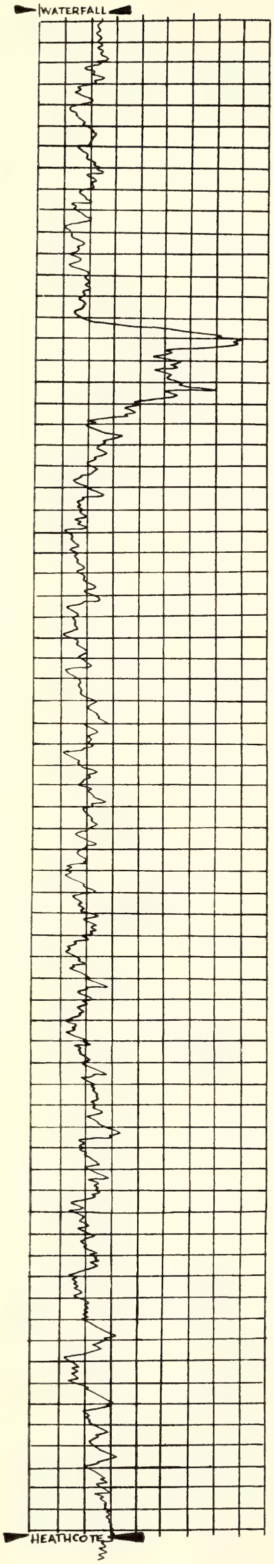

Fig. 2.—Traverse record—radioactive laterite deposit.
Traverse extends from Waterfall to Heathcote.

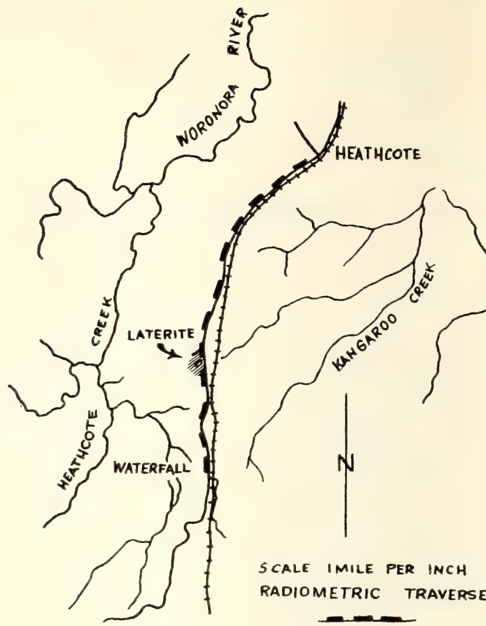

Fig. 1

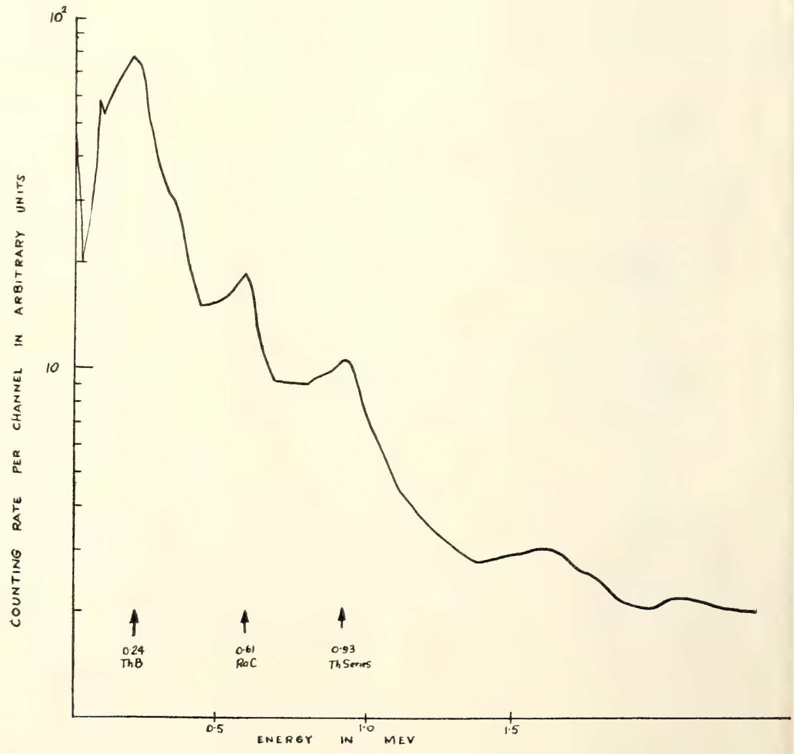

Fig. 3
Gamma ray spectrometry pulse height distribution.

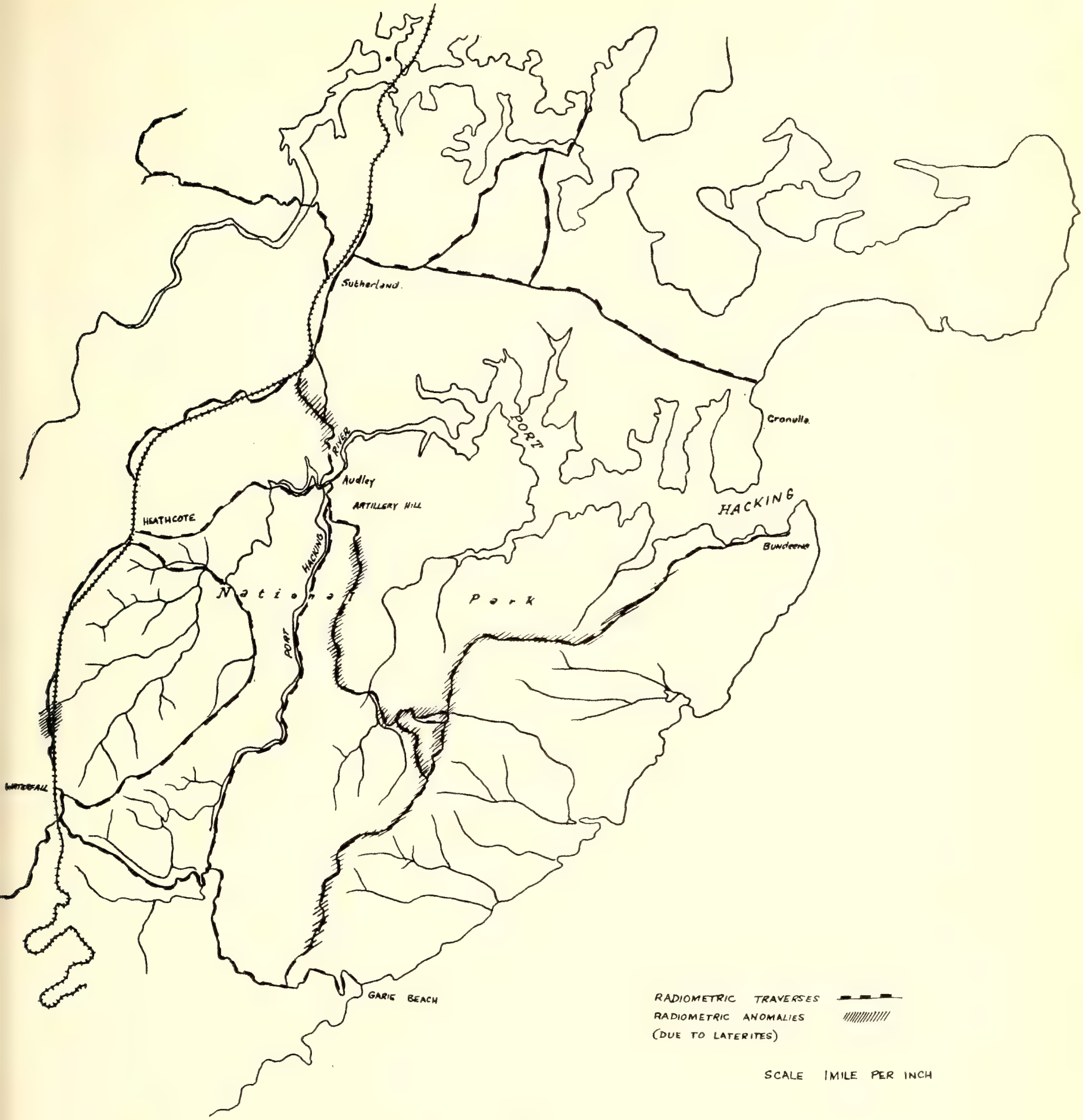

FIG. 4

Radiometric traversing showed that large areas of radioactivity are associated with laterite cappings in the National Park area (see Fig. 4).

Measurements of the radioactivity of the laterite show that the readings are erratic and quite variable, and activity up to 14 microroentgens per hour was recorded in traversing.

The normal levels for the adjacent Hawkesbury sandstone was of the order of 5 microroentgens per hour.

Gamma-spectrometry measurements showed that the radioactivity was due to a thorium mineral being present. A small contribution was due to the presence of radium C (see Fig. 3).

Nature of Laterite

This laterite forms an extensive capping upon the Hawkesbury sandstone in the area investigated. It comprises nodular ironstone strongly cemented together. The ironstone consists of sesqui oxide of iron and some kaolin.

Geological studies by various investigators suggest that the laterite profile represents an exposed alluvial horizon which was formed under humid and wet conditions, possibly from a shale horizon on the Hawkesbury sandstone.

Conclusion

Anomalous surface gamma-ray intensities were located while conducting a programme of measurement of the characteristic levels of gamma-ray intensities in the National Park area. The radioactivity was found to be associated with extensive areas of laterite capping on Hawkesbury sandstone and investigations show that the radioactivity was due to the presence of a finely divided thorium mineral with a small contribution from radium C-bearing mineral.

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The Mesozoic Age of the Garrawilla Lavas in the Coonabarabran-Gunnedah District

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Abstract—The purpose of this paper is to place on record field evidence confirming the conclusion, reached by E. J. Kenny in 1928, that extrusive basic lavas occur as interbedded flows in Mesozoic rocks in the Coonabarabran-Gunnedah district. The history of geological work and conclusions regarding the age of the Garrawilla Lavas is reviewed, and results of recent field investigations are presented.

Original Surveys and Conclusions

In 1927 and 1928, E. J. Kenny of the Geological Survey of New South Wales carried out a preliminary geological survey of the Coonabarabran-Gunnedah district. Results of his survey first were published in summary form in Annual Reports of the Department of Mines in 1928 and 1928 (Kenny, 1928, 1929). The manuscript of a complete report was prepared in 1929, under the title of "Geological Survey of the Coonabarabran-Gunnedah District with Special Reference to the Occurrence of Subsurface Water." This report, including Kenny's original map, has now been published as New South Wales Department of Mines, Geological Survey, Mineral Resources No. 40 (Kenny, 1963).

In the foregoing publications, amongst other results, Kenny recorded his conclusions that contemporaneous basalt flows, which he termed the "Garrawilla Lavas", occurred interbedded between "rocks of Lower Mesozoic age and beds of undoubted Jurassic age". He described the Garrawilla Lavas as lying conformably upon the Napperby Beds, probably of Triassic age, and overlain disconformably by the Purlawaugh Beds and Pilliga Sandstone of Jurassic age. From this it was inferred that the age of the Garrawilla Lavas was either late Triassic or early Jurassic.

Kenny described and mapped the outcrop of Garrawilla Lavas over a relatively wide area extending from Binnaway and Coonabarabran, east to Tambar Springs and Spring Ridge, and north-east through Rocky Glen and Mullally to within about ten miles of Gunnedah. Throughout this area (see Fig. 1), but particularly on its western, north-western and southern sides, his maps show Garrawilla Lavas outcropping from beneath areas of Purlawaugh Beds and Pilliga Sandstone. To the east of Tambar Springs and Mullally, within the area of the Liverpool Plains, where overlying Jurassic sediments have been removed by erosion, Garrawilla Lavas are shown covered in places by extensive sheets of Recent alluvium. Flows of Tertiary basalt, from the Warrambungle Mountains on the west, and the Liverpool Range on the south, are shown extending across the top of the Jurassic sediments into the area of outcrop of Garrawilla Lavas. In some places Tertiary basalt flows are shown overlapping Jurassic sediments on to the Garrawilla Lavas.

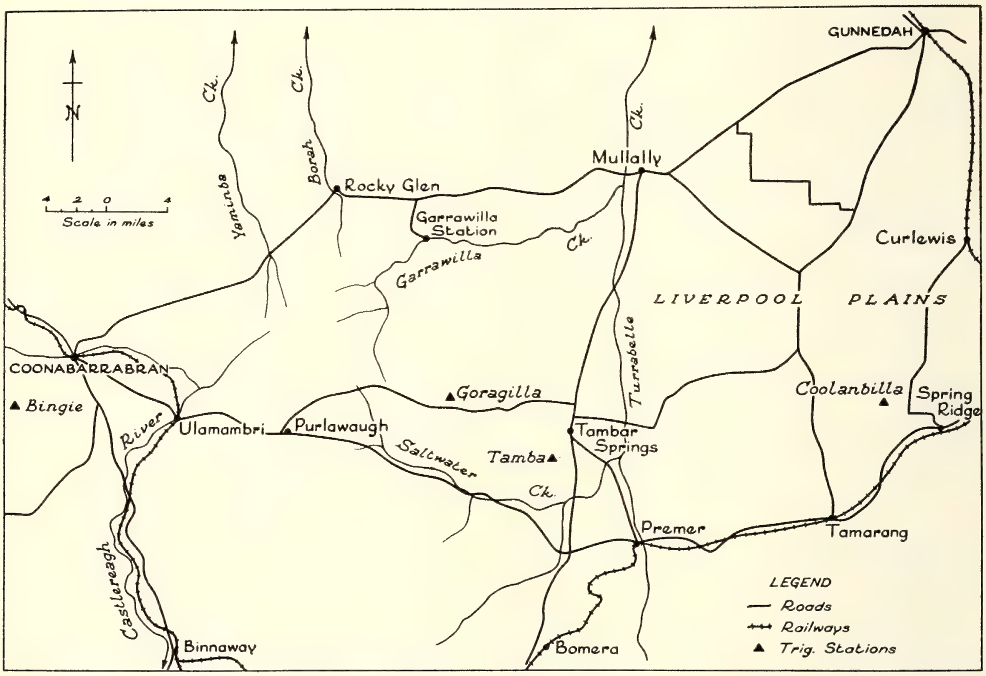
Kenny also describes the widespread occurrence of medium to coarse grained intrusive rocks in the form of large sills, probably of Tertiary age, associated with the Garrawilla Lavas, particularly in the north-eastern portion of the area.

Before commencing work in the Coonabarabran-Gunnedah district, Kenny had already completed a survey of the Dunedoo-Binnaway area (Kenny, 1928*a*). Following the mapping of the Coonarababran - Gunnedah district, extensive surveys of Permian and Mesozoic strata were carried out by other geologists in areas to the south-east, south and south-west. These include the Dubbo-Cobborah area (Lloyd, 1935), the Merriwa-Murrurundi district and south-eastern Liverpool Plains (Dulhunty, 1939*a*), and the Gulgong-Coolah district (Dulhunty, 1939*b*).

The Mesozoic stratigraphy of all adjacent areas was satisfactorily correlated with that of the Coonabarabran-Gunnedah district (Kenny and Lloyd, 1935; Dulhunty, 1939*b*). The Purlawaugh Beds, with their characteristic and persistent "red-bed" lithology, were followed

into all adjacent areas, but contemporaneous flows of Garrawilla Lavas were not actually recognized beyond the limits of the Binnaway-Coonabarabran-Gunnedah-Spring Ridge district. It was considered, however, that the highly ferruginous and " basic " or tuffaceous nature of the Purlawaugh Beds, and equivalent strata in nearby areas, was probably due in part to the influence of contemporaneous volcanic activity, either by addition of pyroclastic material or basalt weathering-products, to the fresh-water lake sediments.

In 1944, Mulholland (1950) published a review of the southern Intake Beds of the Great Artesian Basin. In this work he accepted Kenny's original definition of the Garrawilla Lavas as contemporaneous interbedded Mesozoic lava flows, and illustrated their mode of occurrence in a regional section across the Coonabarabran-Gunnedah district.



Recent Work and Opinions

Throughout the years that have followed the original descriptions and mapping of Mesozoic rocks in the Coonabarabran-Gunnedah and adjacent district, a certain degree of scepticism has arisen in the minds of some geologists regarding the Mesozoic age of the Garrawilla Lavas. Doubt not only exists as to whether all the flows are Mesozoic, but also as to whether, in fact, any of the flows originally mapped as Garrawilla Lavas represent Mesozoic extrusives or Tertiary basalt flows.

In the preparation of an amended Geological Map of the State (1962) by the New South Wales Department of Mines, some basalt flows in the Mullally and Spring Ridge areas, originally mapped as Garrawilla Lavas, were redefined and shown as Tertiary flows. However, G. Rose of the Geological Survey of New South Wales (Rose, 1963), later pointed out that whilst " the Garrawilla Lavas are considered by some workers to be flows and sills of Tertiary age, this is not yet substantiated over the whole area, or the type area, of the Garrawilla Lavas, and conclusive proof either way requires further mapping ".

Wilshire and Standard (1963) examined a small area in the Mullally-Rocky Glen district, in which they concluded that all the basalt flows were of Tertiary age, and overlay Permian sediments. In discussing the regional geological setting of the area, they stated that " Kenny considered the lavas to be interbedded with sediments of lower Mesozoic age ", and that " detail mapping has shown this to be incorrect, and that the lava flows everywhere oveilie the sediments ".

The area examined by Wilshire and Standard is situated almost in the centre of the major area of outcrop of the Garrawilla Lavas, on a pronounced structural high where overlying sedimentary rocks have been removed by erosion. In these circumstances field evidence of the Mesozoic age of the lavas would be difficult to appreciate.

It appears that Wilshire and Standard may not have examined in detail the western and southern margins of the area of basalt outcrop, near Rocky Glen and Tambar Springs (beyond the limits of their area) where relations between the basalt flows and adjacent Mesozoic sediments can be seen to good advantage. Also, in their assumption " that the lava flows everywhere overlie the sediments ", it is possible that they may have included some of the Jurassic Pilliga Sandstone on the western side of their area, with sediments, in which they recorded the presence of glossopteris, exposed beneath the lavas by dissection on the structural high further to the east.

Confirmation of Original Conclusions

In 1963, the present author commenced a very critical and detailed investigation of field evidence bearing on the age of the Garrawilla Lavas throughout the Coonabarabran-Gunnedah-Spring Ridge region. During the first stage of this work a careful examination was carried out of all areas in which the lavas occur adjacent to Mesozoic sedimentary rocks and detailed investigations were made along actual field boundaries between the lavas and sediments. As a result of this work, the author is now convinced, beyond all doubt, of the correctness of Kenny's conclusions that Garrawilla Lavas occur as interbedded flows, outcropping from beneath lower Mesozoic sediments along the margins of the basalt areas within the region of his original maps. The author is also convinced that Kenny's maps, of field boundaries between the lavas and lower Mesozoic sediments, are correct and accurate in all significant details.

In places, such as the country between Mullally and Tambar Springs, and over parts of the Liverpool Plains, basalt flows extend from marginal outcrops over wide areas from which all overlying Mesozoic sediments have been removed by erosion. In such areas it is very difficult to confirm the Mesozoic age of flows and to distinguish between Garrawilla Lavas and Tertiary flows, which in places were extruded after the removal of Mesozoic sediments. It is anticipated that further work on petrology of the lavas, stratigraphy of the flows, and possibly radioactive dating, will eventually lead to a complete differentiation of basalts of the two ages and a clearer regional picture of the extent of Mesozoic vulcanism. At this stage, however, it is quite definite that basic, Mesozoic lavas do occur over a wide area in the Coonabarabran-Gunnedah district, and the following field evidence is submitted in support and confirmation of their occurrence.

(1) Everywhere throughout the entire area of occurrence, the trend of the boundary between Garrawilla Lavas and Mesozoic sediments is strictly related to structure and stratigraphy of the sediments, and in some places to Mesozoic relief on the " pre-Purlawaugh " surface of the lavas. In no case is it related to Tertiary topography, as would be the case if the lavas were of Tertiary age, occurring as flows filling Tertiary valleys. The close relationship between the trend of the boundary and sedimentary structure is seen to best advantage in valleys, such as those of the headwaters of Saltwater and Yaminba Creeks, which have dissected gently-dipping Pilliga Sandstone and exposed underlying Purlawaugh Beds and associated Garrawilla Lavas. In such places, the boundary of the lavas, and the well-defined base of the Pilliga Sandstone, run parallel and rise together across valley sides to the general level of the surrounding country, where they continue as parallel outcrops, in the general strike-direction of the sedimentary rocks. This is a simple and well-known relationship of structure and outcrop to contour, which confirms the interbedded nature of the lavas.

Where relief occurs on the " pre-Purlawaugh " surface of the lavas, there is marked disconformity between the lavas and overlying sediments. In some places this has resulted in overlapping of the Purlawaugh Beds by Pilliga Sandstone on to the lavas. However, the regional dip of the lavas remains parallel to that of the sediments. Basalt flows of undoubted Tertiary age do occur, as shown on Kenny's original maps, at several places such as Coolanbilla, Tamba and Bingie Trigonometrical Station, and in the parish of Urabrible to the south of Coonarabran. In all cases it is quite evident that such flows lie on Tertiary erosion surfaces, across outcrops of Pilliga Sandstone and Purla-

waugh Beds, that their boundaries are determined by Tertiary topography and post-basalt erosion, and are in no way related to structure or stratigraphy of the underlying Mesozoic sediments.

(2) Over most of the district surface relief is low, and valleys are wide and shallow. Where basalt occurs in such valleys, it is very difficult to ascertain, by casual field inspection at isolated points, whether the basalt is a residual of a Tertiary flow filling the valley, or an interbedded Mesozoic flow outcropping on the sides and floor of the valley. In such circumstances it is necessary to study relations of outcrop to structure and contour, to appreciate the true situation. It seems highly probable that casual field inspection, without appreciation of the regional picture, has contributed to the incorrect assumption that the Garrawilla Lavas are of Tertiary age.

Whilst surface relief is generally low, there are, however, several places in the district where erosion on valley sides has provided exposures in which the lavas can be seen actually outcropping from beneath Mesozoic sediments. In the lower reaches of Saltwater Creek the outcrop of the top of the Garrawilla Lavas can be seen separated by about 10 feet of brown clay from an overlying sandstone unit in the Purlawaugh Beds. Exposures of this section occur on J. S. Darling's property " Carnamah " in Portions 15, 16 and 20, Parish of Wilson, and on L. G. Thompson's property " Tallawong ", in Portions 31 and 32, Parish of Saltwater.

Four miles from Coonabarabran, on the northern side of the Ulimambri road, in the vicinity of Portions 90, 108 and 111, Parish of Coonabarabran, the outcrop of the top of the Garrawilla Lavas can be seen in creek beds separated by about eight feet of soft yellow puggy clay from 18 inches of soft white conglomerate at the base of the Pilliga Sandstone. On the southern side of the road at this place, Tertiary basalt flows occur on top of the Pilliga Sandstone.

About 16 miles from Coonabarabran on the Rocky Glen road, at P.W.P. 107, Parish of Mamum, on the western side of the valley of Yaminba Creek, the top of the Garrawilla Lavas is separated from massive Pilliga Sandstone by 15 feet of soft, yellow-brown limonitic clay with thin bands of hard yellow chert.

Some four miles north-east of Rocky Glen, on E. R. Shannon's property " Balmoral ", in the vicinity of Portions 111 and 293, Parish of Girriwilli, there are excellent exposures of the top of the Garrawilla Lavas outcropping from beneath the base of the Purlawaugh Beds which are 60 feet thick and overlain by the Pilliga Sandstone.

At several points along the Tambar Springs-Goragilla road, where it forms the boundary between the Parishes of Urangera and Wilson, there are good exposures of the outcrop of the top of the Garrawilla Lavas, separated by 10 to 20 feet of clay from 40 feet of sandstone in the Purlawaugh Beds, about 100 feet below the base of the Pilliga Sandstone.

The occurrence of from 5 to 20 feet of soft, reddish-brown to yellow, puggy clay between the top of the Garrawilla Lavas and overlying sedimentary rocks of the Purlawaugh Beds or Pilliga Sandstone, is very persistent throughout the district. The junction between the lavas and the overlying clay, frequently appears as a transition rather than a sharp change. This suggests that the clay, which is probably a weathered mudstone, represents products of contemporary weathering of the upper surface of the lava before, and immediately after, the deposition of Mesozoic sediments.

(3) As described originally by Kenny, sills of doleritic material, probably of Tertiary age, are associated with the Garrawilla Lavas in some places. The presence of intrusive sill rocks appears to have been responsible for suggestions that all the Garrawilla Lavas may be sills rather than lava flows. There is, however, an abundance of field evidence, placing beyond all doubt the fact that they are lava flows, as follows :

(*a*) Nowhere is there any indication of contact metamorphism above the Garrawilla Lava flows. As already described, the lava passes by gradation into a soft mudstone which is followed in turn by normal shales or sandstone.

(*b*) Amongst the Garrawilla Lava there commonly occur highly vesicular and amygdaloidal basalt flows up to 100 feet in thickness.

(*c*) At a number of places, including exposures where the Garrawilla Lavas can be seen outcropping from beneath Mesozoic sediments, beds of bole, from 10 to 20 feet in thickness, occur between

some of the flows. These occurrences exhibit all the features of bole beds normally associated with extrusive, basic igneous flows.

Acknowledgements

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Clay Mineralogy of some Upper Devonian Sediments from Central New South Wales

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Abstract—The clay mineral fraction of 48 sediments from the Upper Devonian of central New South Wales has been determined using standard X-ray and petrographic techniques. The clay deposited in the Upper Devonian sediments consists mainly of illite, chlorite and montmorillonite with a little kaolinite. Impermeable shales and siltstones generally have a significantly different clay mineral content compared to the more permeable, associated siltstones and sandstones where post-depositional degradation processes have formed mixed-layered illite, chlorite and montmorillonite minerals and resulted in the precipitation of kaolinite from solution. A higher chlorite content in the east is probably due to a large proportion of weathered volcanic rocks in the source area, whereas a higher illite content in the west is probably the result of the source rocks being rich in quartz and mica.

Introduction

In the following investigation, approximately 50 outcrop samples of shales, siltstones and sandstones from the Upper Devonian of central-western New South Wales were examined by X-ray diffraction to ascertain both the original clay composition at the time of lithification and the amount of alteration to this clay due to post-lithification changes.

Sample Selection and Preparation

Forty-eight samples of shales, siltstones and sandstones were selected from outcrops of the Catombal Group in the Wellington-Molong district (Conolly, 1963), the Hervey Group in the Peak Hill-Parkes-Grenfell-Weddin Range area (Conolly, 1965*a*, 1965*c*), and the Cocoparra Group in the Naradhan-Rankins Springs district (Conolly, 1965*c*) (Fig. 1). Although all samples were weathered to some extent, the effect was minimised by the collection of large samples and selection of the freshest parts during the crushing operation. The list of samples with their lithology described is given in Table 1.

Each sample was crushed with a pestle and mortar, and sieved through a Tyler 100 mesh screen. Approximately 20 to 40 grammes of the clay were dispersed in water and the suspension allowed to settle for the required period (Jackson *et al.*, 1950) before drawing off the fraction less than two microns in diameter. Oriented samples were prepared on glass slides from this fraction.

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X-Ray Diffraction and Determination of Clay Minerals

Each sample, which consisted of an orientated aggregate of clay on a glass slide, was X-rayed four times ; firstly without further treatment ; secondly upon glycolation ; thirdly after heating to 450° C for one half to two hours ; and fourthly after heat treatment to 600° C for half an hour. The various clay minerals were identified using the following criteria :

Kaolinite and chlorite : Kaolinite was easily distinguished from other clay minerals with the exception of some chlorites. The criteria used to distinguish kaolinite from chlorite have been outlined by Bradley (1954) and later by Smoot (1960). According to these authors, well-crystallised chlorite exhibits sharp first, second and third order peaks at 14, 7 and 4·7 Å, but after heat treatment to 575° C, the 14 Å peak is intensified whereas the 7 and 4·7 Å peaks are less distinct.

Kaolinite, on the other hand, loses its structure after heat treatment to 480° C for half an hour due to dehydroxylation. Hence upon glycolation and after heat treatment to 450° C, the 7 Å peak is unchanged but after further heat treatment to 600° C the 7 Å peak disappears. (Fig. 3).

Illite : Smoot (1960) recognised two groups of illite. The first, a well-crystallised, non-expandable material is characterised by sharp peaks at 10 and 5 Å. The diffraction patterns of these illites are similar to muscovite, although the clay minerals generally have a weaker second-order reflection at 5 Å (Fig. 2). The

second group is characterised by a basic mica structure with a small amount of mixed-layered material.

Montmorillonite : Montmorillonite minerals are distinguished by peaks in the range of 12 to 14 Å which expand to 17 Å after saturation with glycol in a normal humidity state. After heat treatment to 450° C the mineral completely collapses to give a peak at 10 Å (Fig. 2).

Mixed-Layer Clay : Mixed-layer clay minerals are usually identified by reflections which are combinations of the reflections of the clay minerals making up the mixed-layer. Generally, the mixed-layer clay minerals in sediments are random structures which give broad reflections over a range of 2θ values, on the diffraction pattern. Mixed-layer clay minerals are virtually absent from the samples investigated in this study. Sometimes a very small amount of random mixed-layer clay is associated with illite and, where present it has been included with the illite.

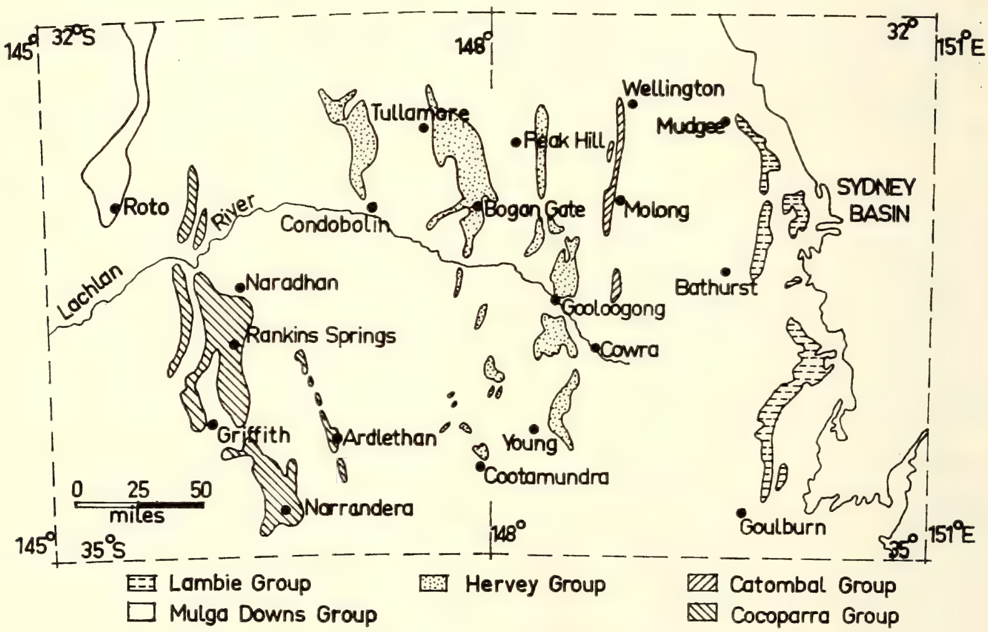


FIG. 1

Geological sketch map of central New South Wales showing the outcrop distribution of Upper Devonian sediments.

Quantitative Estimates of Clay Mineral Composition

Various papers have been published in the last decade dealing with quantitative estimates of clay minerals including those by Johns, Grim and Bradley (1954), Murray (1954), Weaver (1958) and Schultz (1960). Schultz (1960) has described a method which can be used with a fair degree of accuracy for the common clay minerals in ancient sediments. Schultz reported that chlorite was the only clay mineral for which no consistent method could be found. The writer has used the system outlined by Schultz which is briefly summarised as follows :

a. The height intensities of the 7 Å (001) of kaolinite and the 10 Å illite material are measured.

b. Heat treatment to 600° C collapses the structure of the montmorillonite material and hence the intensity of the 10 Å at 20° C is subtracted from the 10 Å intensity at 600° C, to give a peak height for montmorillonite. The illite and montmorillonite peak intensities are multiplied by two and the kaolinite peak intensity by one. The amount of mineral present is then proportional to the new peak intensities.

c. The chlorite content is shown in relative values only. In Table 1, a strong 14 Å line, reflecting a high relative percentage of chlorite, is indicated by three plus sign.

TABLE I

Rock Type	Sample no.	Formation	Colour	Median Grain Size in mm.	Percent Clay	Percent Rock Fragments	Kaolinite	Illite	Chlorite	Montmorillonite
		CATOMBAL GROUP								
Shale ..	216	Kurrool Fm.	green	0·01	60	—	tr.	10	+++	
Shale ..	200	Kurrool Fm.	green	0·01	65	—		10	+++	+
Shale ..	212	Macquarie Park S.S.	green	0·01	50	—	1	9	+++	
Siltstone ..	208	Kurrool Fm.	white	0·03	18	27	6	4		
Siltstone ..	144	Kurrool Fm.	white	0·06	25	5	4	6		
Siltstone ..	193	Macquarie Park S.S.	red	0·07	20	10	6	4		
Fine sandstone	178B	Macquarie Park S.S.	red	0·2	15	12	6	4		
Fine sandstone	149	Macquarie Park S.S.	white	0·15	14	11	6	4	+	
Fine sandstone	154	Macquarie Park S.S.	white	0·5	22	11	4	6	+	
Fine sandstone	148A	Brymedura S.S.	buff	0·4	15	20	5	5	+	+
Fine sandstone	148B	Brymedura S.S.	white	0·4	11	16	6	4	+	+
		HERVEY GROUP								
Shale ..	516	Mandagery S.S.	red	0·01	70		tr.	10	+++	
Shale ..	415	Weddin S.S.	green	0·01	70		1	9	+++	+
Siltstone ..	586	Bumberry Fm.	buff	0·04	20	10	3	7		
Siltstone ..	587	Bumberry Fm.	red	0·06	16	13	2	8	+++	
Siltstone ..	565	Bumberry Fm.	brown	0·06	35	20	4	6	+++	
Siltstone ..	566	Bumberry Fm.	brown	0·06	15	17	3	7	+++	+
Fine sandstone	559	Mandagery S.S.	buff	0·1	4	16	3	7	+	++
Fine sandstone	520	Mandagery S.S.	green	0·1	38	8	3	7	++	+
Fine sandstone	563	Bumberry Fm.	white	0·1	17	2	6	4	+++	+
Fine sandstone	384	Caloma S.S.	white	0·12	19	3	7	3		
Fine sandstone	385	Caloma S.S.	buff	0·13	15	3	6	4		
Fine sandstone	578	Mandagery S.S.	red	0·15	14	10	5	5		
Fine sandstone	549	Mandagery S.S.	pink	0·2	10	15	7	3		
Fine sandstone	510	Mandagery S.S.	white	0·2	1	1	4	6		
Fine sandstone	423	Mandagery S.S.	white	0·2	13	9	1	9	+++	+
Fine sandstone	507	Boona S.S.	white	0·2	12		2	8		
Fine sandstone	595	Bumberry Fm.	red	0·2	20	18	3	7	+++	
Fine sandstone	550	Bumberry Fm.	white	0·2	8	11	4	6		
Fine sandstone	391	Pipe Fm.	buff	0·2	7	3	6	4	+	+
Fine sandstone	386	Burrill Fm.	brown	0·2	14	1	4	6		
Fine sandstone	389	Mandagery S.S.	red	0·33	13	18	1	9		
Medium sandstone	428	Weddin S.S.	white	0·5	5	2	6	4		
Medium sandstone	506	Boona S.S.	white	0·6	2		4	6		
Medium sandstone	591	Bumberry Fm.	brown	0·8	12	42	2	8	++	
		COCOPARRA GROUP								
Fine sandstone	483	Womboyne Fm.	white	0·1	20	5	4	6		
Fine sandstone	482	Womboyne Fm.	white	0·1	16	6	4	6		
Fine sandstone	492	Womboyne Fm.	red	0·2	8	4	3	7		
Fine sandstone	489	Rankin Fm.	white	0·22	2	1	10			
Fine sandstone	476	Ardlethan S.S.	brown	0·2	17	10	2	8	+	+
Fine sandstone	501	Rankin Fm.	red	0·25	18	5	3	7		
Fine sandstone	499	Rankin Fm.	brown	0·3	14	15	2	8	+	+
Fine sandstone	487	Rankin Fm.	white	0·3	15	30	4	6		
Fine sandstone	491	Rankin Fm.	brown	0·4	4	7	2	8		
Fine sandstone	463	Rankin Fm.	white	0·4	2	6	5	5		
Fine sandstone	468	Barrat Conglomerate	white	0·3	8	4	3	7		
Fine sandstone	469	Barrat Conglomerate	white	0·4	4	2	3	7		
Medium sandstone	486	Rankin Fm.	white	0·7	4	6	7	3		

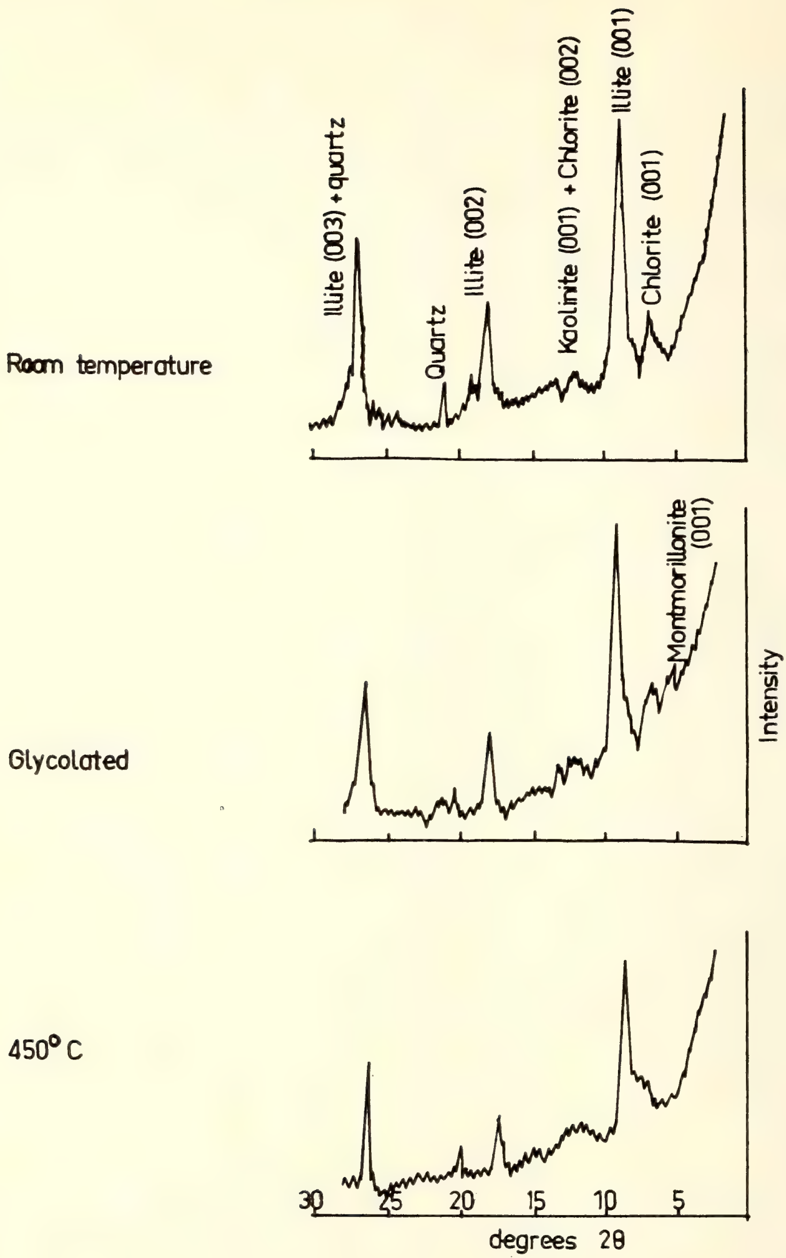


Fig. 2

X-ray diffractometer patterns (Cu radiation) of the clay fraction of a green shale from the Catombal Group (sample no. 200).

Where the 14 Å reflection was moderate or weak, two or one plus signs only are used. In order that some quantitative assessment could be made of the amount of chlorite present in the sediments, a method used by Smoot (1960) was adopted. The ratio of chlorite to illite was found by multiplying the 001 peak intensity for chlorite by a factor of four, and comparing it with the 001 peak of illite at normal intensity. This method was only used where the sample showed high peak

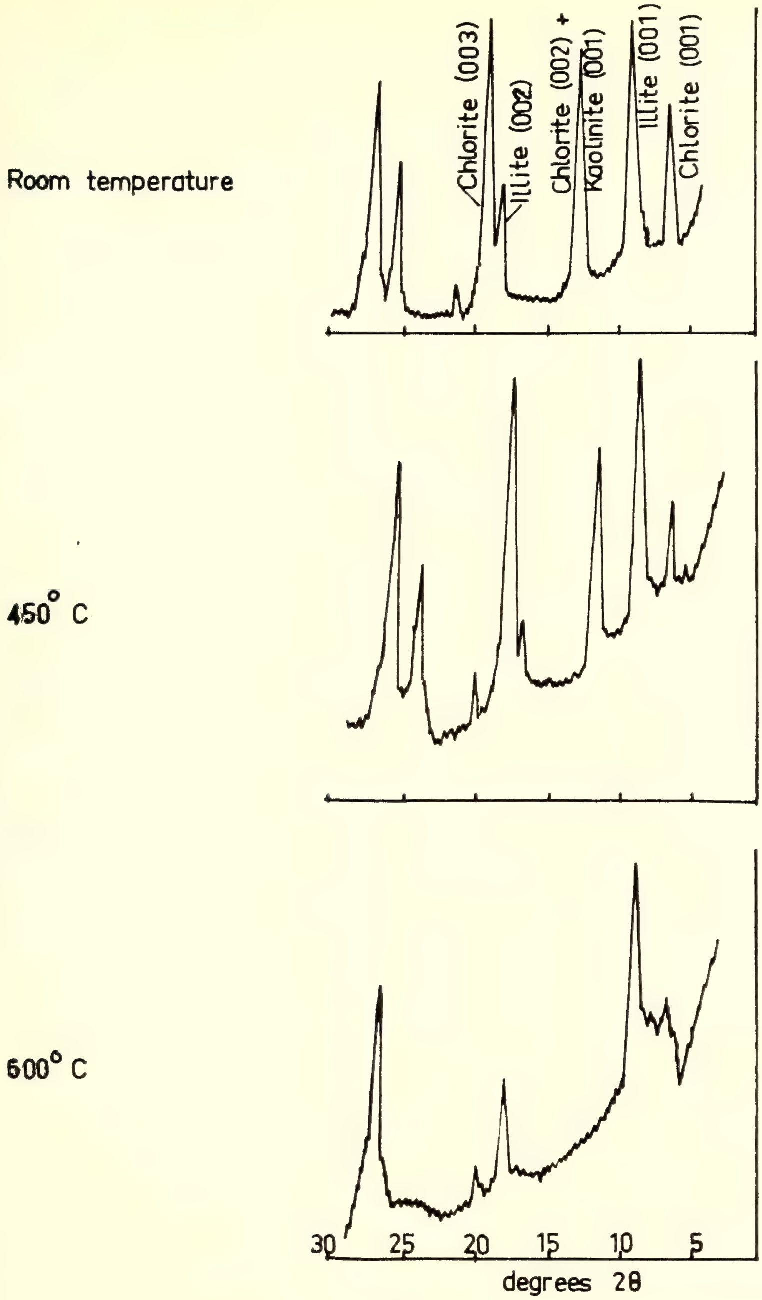


Fig. 3

X-ray diffractometer patterns (Cu radiation) of a lithic sandstone from the Hervey Group (sample no. 595).

intensities for chlorite and hence a relatively high chlorite content, enabling a quantitative assessment of the total clay mineral content shown on the histograms on Fig. 4.

d. Montmorillonite never occurred in large quantities, but the presence of a small 17 Å peak on glycolation was denoted using plus signs in a similar way to chlorite (Table 1).

Petrographic Analysis

Thin sections were cut from each of the samples studied, and a petrographic analyses were made using the point counter method (Chayes, 1956). The percentage clay matrix, rock fragments containing clay, approximate median grain size, and the colour of the sediment was noted and are listed with the clay mineral analyses on Table 1.

Clay Mineral Content of Upper Devonian Sediments

Fig. 4 shows the average clay mineral composition of sandstones, siltstones and shales from the Catombal, Hervey and Cocoparra Groups, obtained by calculating the average composition from the analyses listed on Table 1. In general, shales have a significantly different clay mineral content from that of the sandstones occurring within the same sequence.

THE CATOMBAL GROUP: The shales of the Catombal Group consist of illite, chlorite and some montmorillonite, with very little kaolinite, yet the interbedded siltstones and sandstones have a characteristic kaolinite-illite clay mineral suite with only small percentages of chlorite and montmorillonite (Table 1).

The sediments of the Catombal Group are essentially quartzose and even the siltstones and shales generally consist of 40 to 50 percent detrital quartz. The sandstones vary from orthoquartzites to lithic sandstones (Plates 1 and 2), the majority being protoquartzites with rock fragments and felspar making up 10 to 25 percent of the detrital grains (Conolly, 1963). The clay released during gentle crushing of these sediments is either original clay matrix or is derived from broken clay pellets and rock fragments. The clay released from the shales and siltstones is generally entirely clay matrix, whereas the origin of the clay released from sandstones depended on the composition and texture of the rock.

Petrographic examination of the sandstones shows that orthoquartzites contain very small percentages (less than 10 percent) of rock fragments and generally similar amounts of clay matrix. Pockets of discrete kaolinite " books " occur commonly in these orthoquartzite sands (Plate 2, Fig. 3). Illitic clay patches are generally just as common. The remainder of the clay is derived from crushed rock fragments, shale and siltstone and to a minor extent from weathered acid volcanic rock fragments.

No differences can be readily observed between the clay fractions of the sandstones of the different formations of the Catombal Group. All have approximately equal amounts of kaolinite and illite and about half have small amounts of chlorite and montmorillonite.

THE HERVEY GROUP: Similar results were obtained for the sandstones, siltstones and shales of the Hervey Group (Table 1). There is a gradual transition from low kaolinite and high chlorite in the shales, siltstones and very fine sandstones to high kaolinite and low chlorite percentages in the coarser sandstones.

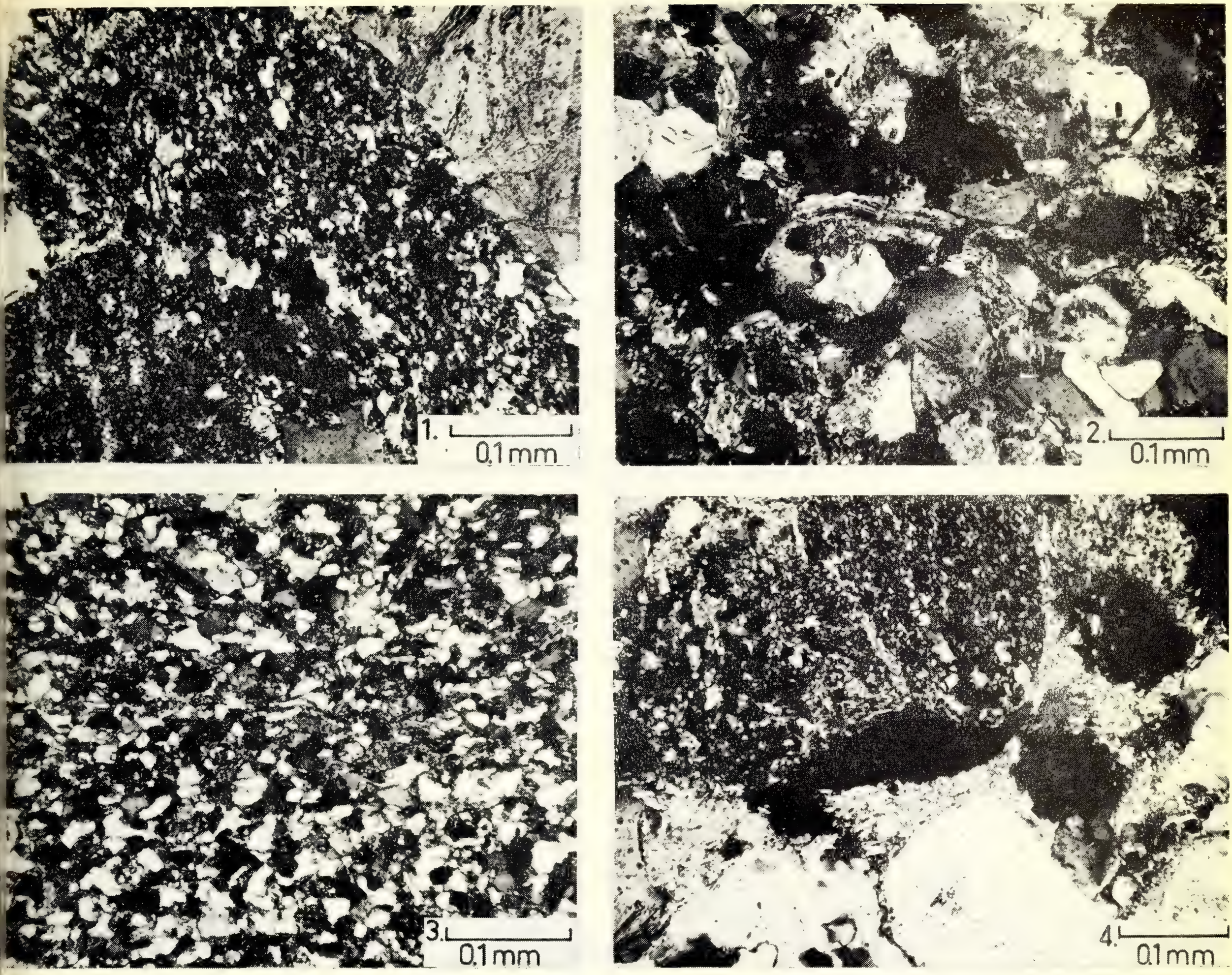
Amongst the sandstones, some of the well-sorted orthoquartzites (Sample Nos. 563, 384, 385 and 391) contain high amounts of kaolinite and some of the lithic sandstones contain significantly high amounts of chlorite and little kaolinite (Sample Nos. 595, 389, 591). Most of the other sandstones lie between these two. There are several exceptions to the above generalisation, for example, the orthoquartzite sandstones from the Boona Sandstone have relatively low amounts of kaolinite. It is suspected that these differences are caused by differences in clay provenance, as the Boona Sandstones outcrop in the Condobolin district west of the area from which the remaining samples were obtained.

THE COCOPARRA GROUP: The sandstones of the Cocoparra Group have a characteristic illite-kaolinite clay fraction, with chlorite and montmorillonite occurring in small amounts in only two samples. Once again, the orthoquartzites contain higher percentages of kaolinite than the more lithic sandstones (Table 1).

Mineralogy and Colour of the Sediments

Although most shales in the Catombal and Hervey Groups are green, some are red. The occurrence of these two different varieties of shale could imply different environmental conditions, however the clay mineralogy remains the same. Examination of the slides in thin-section shows that whereas both varieties of shale contain the green-coloured chloritic clay mineral, the red shales contain so much iron oxide minerals they appear red in colour.

The colour of siltstones and sandstones is mainly caused by the colours of the included rock fragments or their weathered products, or by iron oxide fragments. White siltstones and sandstones are generally orthoquartzites or protoquartzites and contain significantly high proportions of kaolinite (Table 1). The lack of colour is due to the lack of " iron-stained " rock fragments and the green clay minerals, chlorite and montmorillonite (Keller, 1953).



Explanation of Plates

PLATE I

Figure 1 : Brymedura Sandstone, Catombal Group, no. 148A. A fine-grained protoquartzite with most of the rock fragments altered to illite and kaolinite. Fragment in lower left corner is a devitrified acid volcanic rock fragment now greatly altered to kaolinite (light colour) and illite. Large clay area (centre) consists of meshworks of kaolinite filling pore space between quartz grains.

Figure 2 : Mandagery Sandstone, Hervey Group, no. 520. A fine-grained orthoquartzite with a high percentage of clay matrix. Detrital shreds of illite occur " squashed " between subangular quartz grains.

Figure 3 : Kurrool Formation, Catombal Group, no. 216. A quartzose green shale or fine siltstone consisting of 60 per cent illite-chlorite clay and 40 per cent detrital angular quartz.

Figure 4 : Macquarie Park Sandstone, Catombal Group, no. 154. A fine to medium-grained protoquartzite. Consists of rounded to subrounded quartz grains, altered rock fragments and interstitial clay matrix. Rounded grain in upper centre consists of a meshwork of kaolinite surrounded by lighter-coloured illite which forms the interstitial matrix.

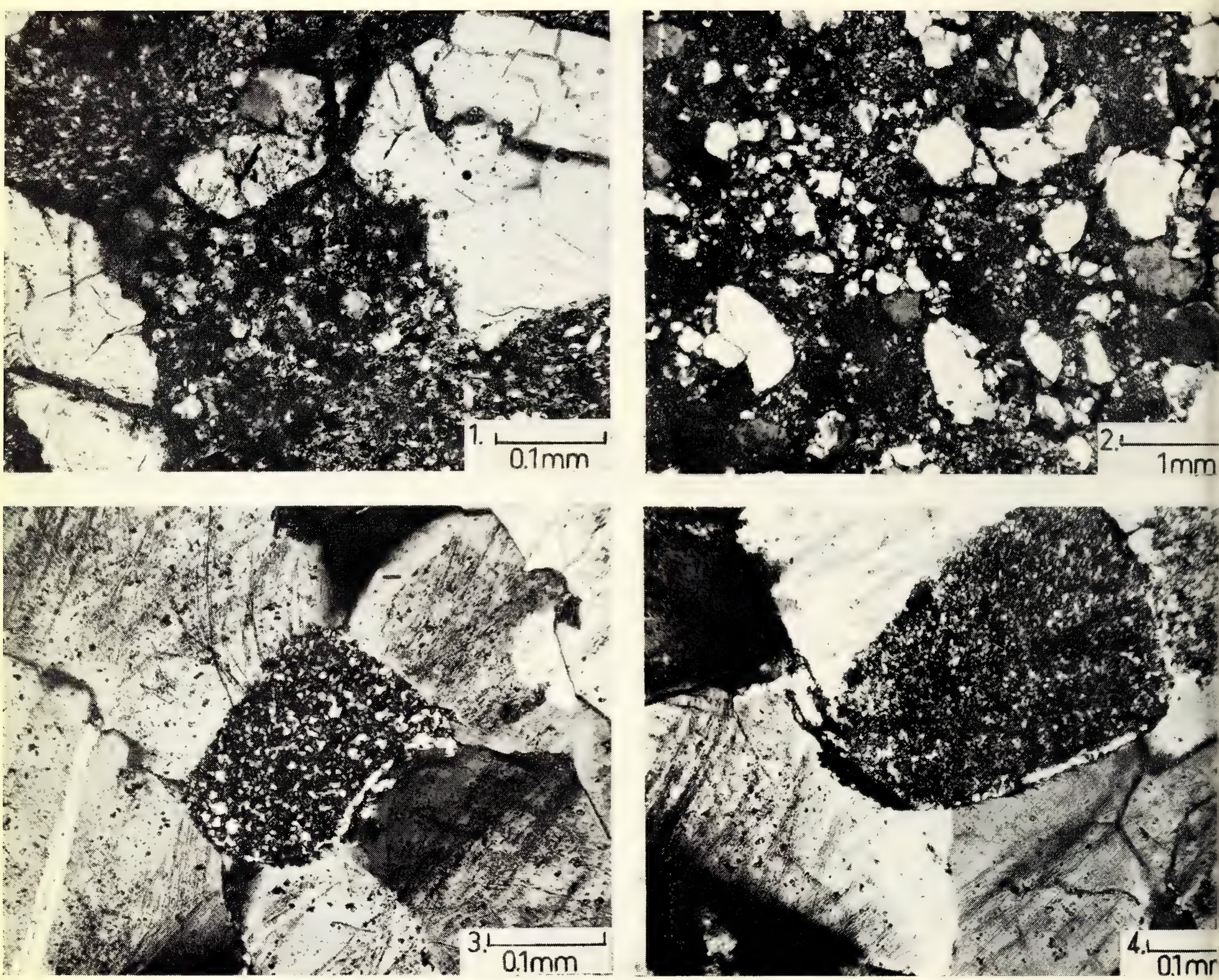


PLATE II

Figure 1: Bumberry Formation, Hervey Group, no. 591. Coarse-grained lithic sandstone. Large amounts of kaolinite and illite clay fill spaces between quartz grains. In upper left and lower right, illitic clay shreds form distinct patches and represent former shale rock fragments.

Figure 2: Bumberry Formation, Hervey Group, no. 591. Coarse-grained lithic sandstone. General view of sandstone texture showing mixture of discrete clay patches (altered shale and silt rock fragments, interstitial clay matrix and subangular to subrounded quartz grains.

Figure 3: Brymedura Sandstone, Catombal Group, no. 148A. Fine-grained, well-sorted, protoquartzite. Quartz grains contain sutured or interlocking boundaries with adjacent quartz grains. A meshwork of kaolinite (centre) or kaolinite "books" fills space between quartz grains.

Figure 4: Brymedura Sandstone, Catombal Group, no. 148A. Protoquartzite with a large rounded shale rock fragment between quartz grains.

The colour of lithic sandstones is mainly the result of the presence of pigmentary iron minerals in the rock fragments, which give the rocks a buff, brown or red colour. However, white lithic sandstones occur in places and are particularly characteristic of the Rankin Formation of the Cocoparra Group (Table 1). The rock fragments in these sandstones are generally altered to illite and kaolinite and there is a lack of iron pigmentation.

Origin of the Clay Minerals

Potter and Glass (1958), Weaver (1958), Smoot (1960), have shown that the clay mineralogy of sandstones and associated finer sediments (siltstones and shales) is different. For instance, alteration of clay minerals in permeable sediments, such as sandstones, occurs after lithification and during weathering. Glass, Potter and Siever (1956) have shown that the outcrop sandstones of some basal Pennsylvanian sediments in Illinois have a clay mineral content of approximately 50 percent kaolinite, 25 percent mica, 15 percent chlorite and the remainder, mixed-lattice clay (10 percent), whereas the associated shales contain only approximately 25 percent kaolinite, 40 percent mica, 10 percent chlorite and 25 percent mixed-lattice clay. In other words, the sandstones contain relatively much more kaolinite and less illite than their associated shales. These authors considered the differences were due to contrasting post-depositional histories induced by contrasting permeabilities. In other words, the clay mineral content of the shales was considered to be almost identical to that at the time of deposition. Presumably the sandstones had a clay mineral content similar to that of the shales at the time of deposition and the differences now evident were due to transformations sometime after deposition. The amount of change in clay mineral content depended upon the quantity of water circulating through the rock and, hence, upon the permeability of the sandstone. The differences between the clay mineral content of fresh outcrop samples of sandstones and shales is a measure of the amount of change that had occurred due to circulating groundwaters after lithification.

Glass (1958) obtained similar results to those of Siever and Potter (1956). He showed that orthoquartzite and subgreywacke sandstones from the Pennsylvanian sediments in Southern Illinois contain relatively more kaolinite than the associated shales. Glass considered the kaolinite formed in the sandstones after exposure. Core samples of sandstones showed the same type of high kaolinite content but to a lesser degree.

Smoot (1960) showed that shale samples of the Pre-Pennsylvanian sediments of the Illinois Basin are composed dominantly of illite and chlorite, whereas the sandstones are composed dominantly of kaolinite, illite and chlorite. Smoot concluded that the clay mineral suites of shales, obtained either from subsurface or surface samples, are those that had been formed about the time of lithification, and have been altered either by weathering at the surface or by circulating formation fluids in the subsurface. Conversely, the clay mineral suites in permeable sandstones are controlled by circulating fluids in the subsurface and by weathering in the outcrops.

If the permeability of the sediment is the main factor controlling the amount of degradation of clay, then there should be a direct relationship between the amount of secondary clay mineral, kaolinite, and the permeability of the rock. For instance, well-sorted orthoquartzitic sandstones are normally more permeable and should therefore be more kaolinitic than argillaceous lithic sandstones and protoquartzites. On the other hand, a decrease in grain size, and hence increase in argillaceous matrix, causes sandstones to become less permeable and, therefore, less kaolinitic.

The sandstones, siltstones and shales of the Hervey and Catombal groups form a natural sequence of permeable—non-permeable rock types. The amount of kaolinite increases from shales to sandstones and it would appear that in these examples at least, permeability was one of the factors controlling kaolinite formation. Similar differences exist for the sediments of the Catombal Group.

Similar mineralogical differences can be observed between the well-sorted orthoquartzitic sandstones and more argillaceous lithic sandstones within the Hervey Group. For instance, the protoquartzites and lithic sandstones of the Bumberry Formation have a different clay mineral suite to the well-sorted orthoquartzitic sandstones of the Caloma Sandstone and the Mandagery Sandstone (Table 1).

The Bumberry Formation sandstones have a higher content of chlorite, illite and montmorillonite clay than the orthoquartzitic sandstones which have a characteristic kaolinite-illite clay mineral suite. However, although there may not be a difference in permeability between these two types of sandstones, there is the possibility that the differences in composition have been induced due to differences

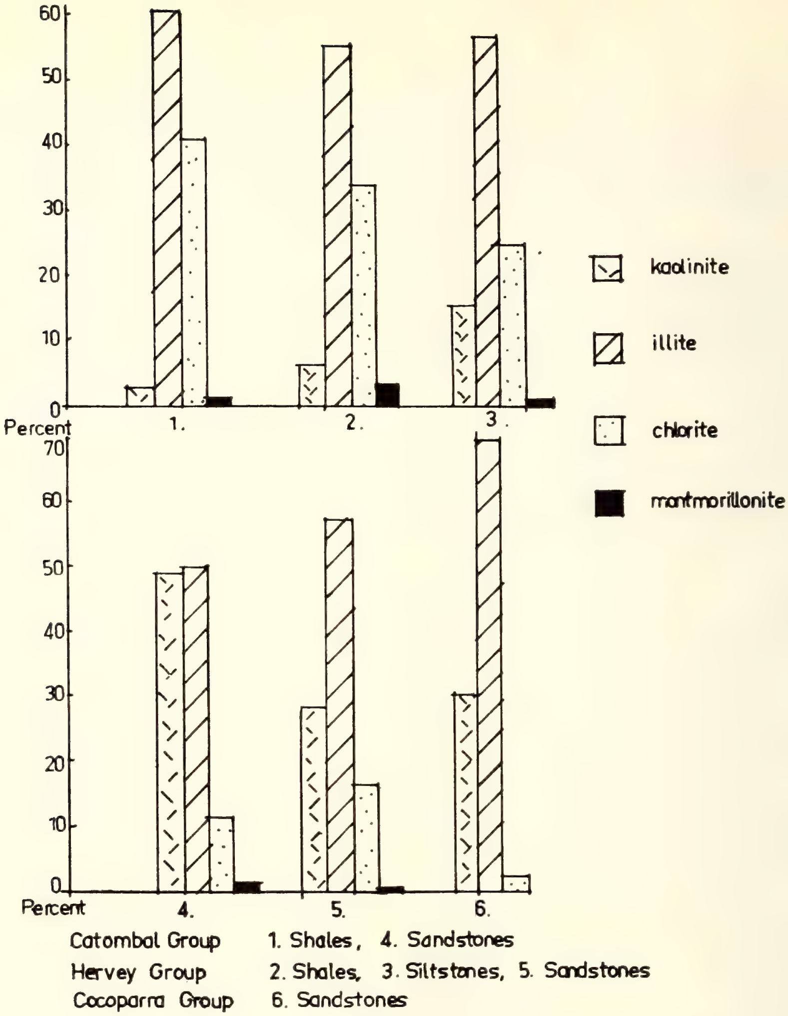


FIG. 4

Average composition of the clay fraction of some Upper Devonian sediments in central N.S.W. The percentages have been calculated after omission of the quartz content from the clay fraction.

in the sedimentary environment and source rocks. In the above example, one of the original controlling factors is the large amount of rock fragments in the Bumberry sandstones. Rock fragments make up at least 50 percent of the clay fraction, and are therefore one of the factors controlling clay mineral composition.

It is considered that differences in clay mineral content between orthoquartzitic and more argillaceous sandstones are basically due to both permeability and clay rock fragment content. This does not imply that there was any change in source rock composition because the clay-bearing rock fragments of the lithic sandstones could have been broken up by greater transportation and reworking to form the clay matrix of the orthoquartzitic sandstones.

The Formation of Kaolinite in Permeable Sediments

The occurrence of meshworks of kaolinite " books " or kaolinite " worms " in sandstones was commonly observed in thin sections of the Upper Devonian sandstones investigated in this study. More frequently, kaolinite occurs as irregular and poorly-crystallised particles between detrital grains (Plates 1 and 2). Since

it has been shown that kaolinite is only present in the permeable siltstones and sandstones, it is concluded that the kaolinite is mainly of a secondary origin.

The clay minerals of these permeable sediments are accessible to percolating water and hence susceptible to intrastratal solution processes. Some of these processes occur during diagenesis and others are due to surface weathering.

Smoot (1960) refers to solution processes during diagenesis and weathering processes. He shows that illite changes to illite plus mixed-layer clay during degradation processes.

Loughnan, Grim and Vernet (1962) studied the weathering of some Triassic shales from the Sydney area, and showed that illite changes to mixed-layered clays, montmorillonite and, with more extensive leaching, kaolinite.

Hence, it is concluded that the clay mineral content of the permeable siltstones and sandstones of the Upper Devonian sediments has undergone similar degradation processes, both during lithification and weathering, with the formation of kaolinite at the expense of illite.

Regional Variations in Clay Mineralogy

Although changes in clay mineral composition occur within a given suite of sedimentary rocks of similar provenance and environmental conditions, changes should also occur between two suites with different provenance and/or environmental conditions. If the clay mineralogy of the Catombal, Hervey and Cocoparra Groups is compared (Table 1, Fig. 4) there are some obvious differences in composition which are probably caused by differences in provenance since the conditions of original deposition and subsequent weathering have been similar for the three groups. For example, although the shales of the Catombal and Hervey Groups have a similar suite of clay minerals, kaolinite is probably less abundant in the former. This slight change in composition may be indicative of different environmental or source rock composition.

Similarly, when the clay mineral suites of the sandstones of the Catombal, Hervey and Cocoparra Groups are contrasted, the following trends are suggested :—

1. Kaolinite becomes less abundant toward the west (from the Catombal to the Cocoparra Group) ;
2. Illite is more abundant in the west ;
3. Chlorite is more abundant in the east.

The sandstones of the Catombal and Hervey Groups with a high rock fragment content also have appreciable amounts of illite and chlorite. Hence it is concluded that the illite and chlorite are mainly contained in the rock fragments and that the high illite-chlorite composition of the associated shales is the original composition of the clay in the source rocks and has not been greatly affected by the environment of deposition.

Similar conclusions have recently been made by Vlodarskaya (1964) in his study of the distribution of clay minerals in Palaeozoic and Mesozoic rocks.

The somewhat higher chlorite content of the Catombal and Hervey Group sandstones is probably a reflection of the higher amounts of weathered volcanic detritus being deposited in these Groups (Conolly, 1962). Further to the west, the source rocks of the Cocoparra Group are mainly sedimentary and have a characteristic high quartz and illite content (folded quartzose Ordovician sands, silts and shales—Conolly, 1962). These source rocks are probably responsible for the relatively higher illite content of the Cocoparra Group sandstones.

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Photographic Observations of Double Stars

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Abstract—Photographic measures are given of 152 double stars. The internal mean error of a measure from one plate is $\pm 0''\cdot 020$ in each of the rectangular coordinates in which the measures were made. Measurements on an artificial double star indicate that photographic effects may be neglected.

This series of double star measures depends on photographs taken with the Melbourne astrographic objective (scale $59''\cdot 32$/mm) to 1956 September 10 and thereafter with the Sydney lens (scale $59''\cdot 76$/mm).

Each plate has a row of about 16 exposures at the centre of the plate with the telescope moved about $0'\cdot 5$ in declination between exposures. Orientation is obtained by taking one exposure with the telescope $4'\cdot 1$ west of the central position and another immediately afterward with the telescope an equal amount east of the central position. These distances are set by lines in the eyepiece graticule. The movement between exposures is effected by means of the quick motion in hour angle. An orientation pair of this kind is taken both before and after the central series. The two values of orientation, obtained separately from these pairs, always agree to an accuracy better than is required for the position angle of the doubles except when the telescope has been bumped during the operations. These plates were rejected.

The exposures have been regulated in each case to give a satisfactory image of the double. The first plate taken on any double has extra exposures of varying lengths and if unsatisfactory it has been rejected and a new exposure time estimated from these extra exposures. To keep the exposures from becoming too long, that is greater than about 30 seconds, or too short a variety of emulsions have been used. Table I lists for the emulsions used the photographic magnitude to which satisfactory images can be obtained in 30 seconds, the mean error in one coordinate of the measurement on a single image and the number of plates on which the conclusion rests.

The plates were all measured in rectangular coordinates on a long screw measuring machine by Hilger and Watts. After measurement of all images in one coordinate the plate is turned through a right angle for measurement of the other. Measurement is also done in the reverse direction for each coordinate. The measurements of the orientation-pairs give the transformation which is used to refer all the results to the equatorial coordinates of the time.

Table I

Emulsion Type	Mag.	Mean Error	Plates
		$''$	
Kodak Lantern . .	6·0	0·072	15
Process, Kodak or Ilford	7·8	0·061	146
Ordinary, Ilford . .	9·0	0·070	17
Ordinary, Kodak . .	9·3	0·098	188
Rapid Process, Ilford (Experimental) . .	9·5	0·069	38
Zenith Astronomical, Ilford	9·8	0·083	6

The standard mean error of Δx and Δy from a single image has been found for each plate. The average mean error thus determined was $\pm 0''\cdot 087$ ($1\cdot 5\mu$) for Δx and $\pm 0''\cdot 082$ ($1\cdot 4\mu$) for Δy. For the average number of images measured on a plate the standard error for the result derived from all images of the plate was $\pm 0''\cdot 020$ in Δx and $\pm 0''\cdot 019$ in Δy. The errors may also be estimated by comparing the results from different plates for the same star and the mean error so derived is $\pm 0''\cdot 028$ in each coordinate. This estimate rests on examination of the results from 304 plates.

The only error of the measuring machine which has been taken into account is the periodic error of the screw. Progressive error of the screw, non perpendicularity of the ways and inaccurate orientation between the axis of the measuring screw and the bisecting line were all considered and could not, in any case, give rise to errors appreciable in the above mean errors. Similarly the effect of differential atmospheric refraction is negligible. All of the plates were taken near the meridian and the effect was calculated for the most unfavourable cases and always found less than a quarter of the mean error for a plate. Magnitude equation has been avoided by selecting pairs for the programme which do not differ too much in magnitude. For the wider pairs (i.e. $d > 10''$) a difference of a little over one magnitude has been permitted and for close pairs, where overexposed primary and underexposed companion might give rise to photographic effects, the difference has been kept below $0^{m}\cdot5$. Table II shows the result of an attempt to correlate the mean error with the magnitude difference and it is clear that the correlation is not strong. Two coarse diffraction gratings, with constant $2\cdot5$ and $3\cdot7$ magnitudes respectively, now exist to assist with this problem.

Table II

Δm	Mean Internal Error for Plate	Plates
	$''$	
$0\cdot0 \leq \Delta m \leq 0\cdot4$	$0\cdot022$	133
$0\cdot4 < \Delta m \leq 0\cdot9$	$0\cdot018$	59
$0\cdot9 < \Delta m$	$0\cdot021$	48

Since the plates were taken without a filter the possible effect of atmospheric dispersion must be considered. A preliminary result of a study being made by H. W. Wood indicates that for our telescope and plate combination Δz is approximately $0''\cdot1$ tan z for a difference of spectral type B8 to K5. This could well produce an effect appreciable in relation to the errors in the measures for stars with large difference of colour between the components and appreciable zenith distance. Since the plates were taken on the meridian the zenith distance is as small as possible and stars which show, on the photographic plates, a big change of difference of magnitude compared with the recorded difference in visual magnitude have been rejected. For most of the measures reported the effect is estimated to be less than half the mean error for a plate. For six stars the effect may be greater than this. They are Δ4 (right ascension 1h 35m), h3715 (4h 57m), h3765 (5h 26m), Δ159 (14h 15m), h3184 (23h 16m) and Cor 261 (23h 42m).

It is known that the distance between two closely adjacent star images may be affected by various photographic effects associated with the drying of the emulsion near an existing image, depletion of developer around a developing image and turbidity of the emulsion. The effects, which have been investigated by Ross (1924), may operate in opposite directions. It was decided to investigate them by photography of an adjustable artificial double star. The photographs were taken with a lens of focal length 340 mms and a stop was inserted so that the focal ratio was the same as in our astrograph. The artificial stars were pinholes in front of an extended light source, pale blue to simulate a colour temperature of about 6,000° K. These were made small so that they subtend an angle at the lens corresponding to less than the Airy disc. Arrangements were made for varying and for measuring the distance between the two pinholes and, by the use of rotating sectors, for varying in a predetermined way the brightness of one component. The artificial double was $57\cdot3$ metres from the camera. The artificial star images were similar to images of real stars taken under good seeing conditions. Series of measurements were made with the stars equally bright and with a difference of brightness of two magnitudes. The exposure which would produce images which would have been acceptable at the telescope was found and the experiment carried on with this exposure and also with exposures of half and twice this duration. Conditions, including development in D19, were made as nearly as possible the same as for plates taken at the telescope. The results are tabulated in Table III. Those under Series (a) are for the stars with equal brightness and those under Series (b) apply to a difference of two magnitudes in the brightness. The column headed d is the distance in millimetres between the images calculated from the measured separation of the artificial double and in the body of the Table is the distance measured on the plate, the results being given for " normal ", half normal and twice normal exposures. Each tabulated result depends on the measurement of ten or more images. For both series the discrepancies between the computed and measured separations of the star images occur only when the distance between the images

TABLE III

Series (a)				Series (b)			
d mm	½N mm	N mm	2N mm	d mm	½N mm	N mm	2N mm
0·027	0·022	0·022	0·018	0·037	0·032	0·031	——
·040	·039	·040	·036	·044	·042	·042	·042
·048	·049	·048	·048	·050	·051	·051	·050
·055	·055	·057	·056	·055	·055	·055	·055
·069	·069	·070	·071	·060	·061	·060	·060
·076	·077	·077	·077				
·142	·142	·143	·143				

becomes less than 0·04 mm. At this stage the images have a tendency to overlap and pointing on them becomes a matter of interpretation by the measurer. This and turbidity effects may well account for the discrepancies which occur at such close distances. The separations of the images of the real stars of the programme was always greater than this and there is no evidence either from these experiments or from comparison with visual results that our photographic results are influenced by systematic effects of the photography.

In Table IV are given the results of measures of 152 double stars on 438 plates. The first four columns give the name of the star, the right ascension and declination (1900·0) and the date of the observation. Columns 5 and 6 give in seconds of arc, the mean errors of Δx and Δy for a single image. Columns 7, 8 and 9 give the number of images measured, the position angle and the distance. I would like to thank Winsome Bellamy (B), W. H. Robertson (R) and H. W. Wood (W) for cooperation with me in this programme. In column 10 under O is given for each plate the initial of the observer at the telescope and under M of the measurer of the plate.

The orbital motion of most of these stars is small and so they do not require frequent observation. One star Δ5 (= p Eridani, R.A. 1h 36m) has an orbit determined by Luyten and Ebbighausen (1934). In this case the observation accords well with the ephemeris and so revision is not needed.

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TABLE IV

Name	R.A.	Dec. S.	Epoch	m.e.x.	m.e.y.	No.	p.	d.	O, M
	h m	° ′					°	″	
h3416	0 59·2	60 38	54·626	±0·075	±0·098	14	128·42	4·988	R, R
			58·648	0·065	0·069	18	128·88	4·964	S, S
Arg4	1 27·6	27 04	60·626	0·063	0·064	22	72·26	18·168	S, B
			60·684	0·052	0·064	23	72·06	18·196	S, B
Δ4	1 34·9	53 57	53·804	0·119	0·140	15	104·54	10·502	S, S
			55·929	0·091	0·094	20	104·37	10·546	S, S
			58·654	0·134	0·107	20	104·42	10·388	S, S
Δ5	1 36·0	56 42	53·818	0·110	0·110	15	202·10	10·318	W, S
			54·626	0·091	0·072	14	201·61	10·395	R, S
			55·930	0·064	0·054	20	201·39	10·404	S, S
			58·648	0·077	0·092	19	200·64	10·474	S, S
			60·625	0·051	0·064	22	200·16	10·581	S, S
HN58	1 54·3	23 24	54·632	0·060	0·075	14	304·06	8·383	R, S
			56·645	0·077	0·088	19	303·71	8·374	S, S
			56·905	0·084	0·069	19	303·32	8·404	S, S

Table IV—*continued*

Name	R.A.	Dec. S.	Epoch	m.e.x.	m.e.y.	No.	p.	d.	O, M
	h m	° ′					°	″	
h3483	2 02·3	71 44	55·932	0·098	0·118	21	277·97	7·194	R, S
			59·943	0·094	0·086	19	277·36	7·240	S, S
			60·762	0·083	0·130	20	277·29	7·124	W, S
h3485	2 07·8	49 48	55·929	0·080	0·092	21	138·76	4·535	S, S
			56·662	0·145	0·122	20	137·88	4·602	R, S
			58·653	0·126	0·104	18	137·96	4·566	S, S
h3488	2 09·5	62 07	56·664	0·138	0·123	20	143·26	5·228	R, S
			58·943	0·088	0·080	21	142·90	5·140	W, S
R14	2 10·7	73 09	53·804	0·116	0·192	14	159·44	10·244	S, S
			54·670	0·075	0·068	20	159·12	10·380	W, S
			55·926	0·075	0·075	20	159·42	10·357	S, S
Cor14	2 35·5	53 23	53·778	0·104	0·110	15	128·36	8·822	R, S
			54·651	0·114	0·110	14	128·36	8·812	S, S
			57·943	0·104	0·115	20	129·23	8·848	S, S
Cor15	2 43·6	67 25	56·662	0·126	0·084	21	197·89	4·591	R, S
			60·973	0·086	0·067	20	197·28	4·582	S, B
h3532	2 44·6	37 49	54·651	0·068	0·079	14	145·16	5·309	S, S
			54·686	0·083	0·079	14	145·32	5·293	R, S
			58·943	0·069	0·050	21	145·43	5·384	W, S
HN18	3 12·8	23 24	53·820	0·141	0·114	14	256·05	8·902	W, S
			54·708	0·141	0·122	14	256·48	8·994	S, S
			60·741	0·104	0·098	20	256·30	8·942	S, S
Δ15	3 36·2	40 41	54·727	0·102	0·110	20	328·30	7·939	W, S
			54·738	0·095	0·106	22	328·18	7·909	R, S
			57·676	0·065	0·046	21	327·87	7·797	S, S
h3596	3 44·6	32 05	58·017	0·073	0·069	22	137·32	9·290	R, B
			58·714	0·054	0·050	19	137·39	9·401	S, B
			60·741	0·051	0·057	18	137·68	9·202	S, B
			60·747	0·048	0·061	22	137·76	9·271	S, B
Δ16	3 44·9	37 56	56·695	0·114	0·091	20	211·90	7·934	R, B
			57·028	0·065	0·054	19	211·73	7·843	S, B
			58·020	0·088	0·061	22	212·14	7·922	S, B
			59·747	0·059	0·070	21	211·61	7·872	W, B
h3611	3 53·1	40 12	58·708	±0·062	±0·104	24	138·90	4·164	S, B
			59·749	0·055	0·052	21	139·40	4·272	W,B
Δ17	3 58·4	54 36	53·820	0·201	0·102	14	13·60	5·358	W, S
			54·725	0·118	0·156	21	13·37	5·398	W, S
			58·020	0·107	0·092	20	13·02	5·371	S, S
h3622	4 01·2	36 07	58·714	0·073	0·054	21	111·51	10·469	S, B
			60·744	0·063	0·054	23	112·36	10·410	S, B
			60·823	0·052	0·032	22	111·98	10·397	S, B
h3634	4 12·2	44 52	54·728	0·114	0·083	20	332·06	11·206	W, S
			54·738	0·133	0·102	21	332·22	11·251	R, S
			57·028	0·134	0·142	21	331·62	11·237	S, S
Rmk4	4 22·2	57 18	54·708	0·056	0·076	14	241·66	5·877	S, S
			54·725	0·072	0·064	20	241·49	5·900	W, S
			57·870	0·065	0·073	21	242·02	5·894	W, S
h3658	4 26·2	49 49	58·017	0·080	0·061	21	120·28	5·620	R, B
			58·708	0·053	0·039	21	120·12	5·679	S, B
			59·842	0·038	0·035	23	121·32	5·494	S, B

TABLE IV—*continued*

Name	R.A.	Dec. S.	Epoch	m.e.x.	m.e.y.	No.	p.	d.	O, M
	h m	° ′					°	″	
h3673	4 29·3	77 54	54·760	0·083	0·068	20	66·76	10·268	S, S
			56·023	0·133	0·083	19	66·48	10·272	S, S
			60·823	0·072	0·034	19	66·82	10·296	S, S
h3686	4 40·4	61 24	57·755	0·077	0·111	20	219·61	7·234	W, B
			58·749	0·056	0·060	20	220·16	7·319	R, B
			59·843	0·046	0·062	22	220·24	7·273	S, B
			60·853	0·094	0·059	21	219·92	7·229	W, S
Hu1376	4 42·9	44 28	53·769	0·102	0·095	14	313·72	5·280	W, W
			53·820	0·126	0·098	14	313·45	5·271	W, S
			56·733	0·145	0·087	21	313·52	5·321	S, S
Δ18	4 48·7	53 38	56·023	0·083	0·079	20	57·76	12·400	S, B
			56·064	0·075	0·083	20	57·52	12·443	W, B
			57·870	0·046	0·038	20	57·68	12·409	W, B
			58·766	0·038	0·054	20	58·26	12·447	S, B
h3715	4 56·9	49 36	54·804	0·126	0·122	20	111·99	9·874	R, S
			56·009	0·126	0·166	26	112·34	9·882	S, S
			59·050	0·100	0·084	21	112·32	9·847	S, S
h3735	5 09·8	32 01	56·796	0·092	0·088	22	151·36	7·106	S, S
			57·080	0·065	0·065	20	151·55	7·164	S, S
			60·744	0·073	0·051	20	151·31	7·176	S, S
h3763	5 23·4	43 28	56·812	0·154	0·104	22	252·40	11·948	W, B
			57·080	0·115	0·107	21	252·58	11·946	S, B
h3765	5 26·4	19 30	53·766	0·095	0·095	14	2·66	22·669	W, S
			54·804	0·091	0·102	20	2·92	22·712	R, S
Δ22	5 28·1	42 23	53·769	0·050	0·087	13	168·67	7·420	W, S
			54·760	0·072	0·056	20	168·64	7·431	S, S
			56·061	0·072	0·060	22	168·34	7·434	S, S
			56·064	0·110	0·083	20	169·18	7·389	W, S
Hd77	5 35·5	20 29	57·870	0·057	0·046	22	122·93	11·138	W, B
			60·094	0·055	0·037	20	123·37	11·071	W, B
			60·124	0·060	0·037	20	123·73	10·994	S, B
Arg12	6 01·2	25 01	58·091	0·061	0·054	18	294·88	4·517	S, B
			59·843	0·086	0·066	23	293·81	4·539	S, B
			60·124	0·038	0·070	24	294·69	4·674	S, B
h3830	6 01·5	28 40	57·080	0·107	0·115	20	2·74	6·308	S, S
			58·119	0·134	0·111	22	2·26	6·325	W, S
			60·820	0·102	0·091	23	2·40	6·348	S, S
Δ26	6 12·0	65 30	53·818	±0·152	±0·160	14	118·47	20·622	W, S
			53·820	0·129	0·160	14	118·37	20·722	W, S
			56·812	0·123	0·111	21	118·48	20·626	W, S
h3871	6 30·3	29 33	59·843	0·101	0·113	23	353·92	7·737	S, S
			60·184	0·101	0·067	20	353·64	7·652	R, S
			60·821	0·077	0·076	21	354·21	7·680	S, B
Δ32	6 38·9	38 18	58·141	0·042	0·031	20	277·06	7·914	S, B
			60·124	0·037	0·037	21	277·06	7·899	S, B
			61·121	0·043	0·032	23	277·19	7·926	W, B
h3898	6 49·1	56 07	58·119	0·107	0·107	20	310·28	16·654	W, B
			60·184	0·078	0·086	20	311·00	16·628	R, B
			61·195	0·067	0·052	23	310·58	16·634	S, B

TABLE IV—*continued*

Name	R.A.	Dec. S.	Epoch	m.e.x.	m.e.y.	No.	p.	d.	O, M
	h m	° ′					°	″	
Rmk5	7 08·4	55 26	58·119	0·077	0·077	20	45·18	7·009	W, B
			58·152	0·080	0·077	22	44·92	6·916	W, B
			58·215	0·041	0·054	21	44·89	7·052	W, B
Rmk6	7 18·0	52 07	57·163	0·027	0·027	20	23·09	9·327	S, B
			58·141	0·054	0·046	21	23·56	9·350	S, B
			59·138	0·058	0·069	21	23·54	9·288	S, B
			59·149	0·092	0·054	27	23·48	9·337	W, B
			60·171	0·033	0·056	23	23·74	9·306	W, B
h3966	7 21·2	37 06	61·163	0·086	0·081	23	142·38	6·968	S, S
			61·215	0·058	0·058	23	142·66	6·940	S, B
Δ49	7 25·0	31 39	61·138	0·062	0·051	25	53·74	8·994	S, B
			61·163	0·052	0·032	25	53·02	8·942	S, B
			61·179	0·044	0·064	21	53·33	9·017	W, B
HN19	7 30·1	23 15	55·223	0·054	0·058	20	113·30	9·595	S, B
			57·163	0·080	0·096	22	113·92	9·621	S, B
			59·215	0·034	0·038	20	114·58	9·713	R, B
h4031	7 56·7	60 35	58·141	0·054	0·042	23	357·13	5·315	S, B
			59·215	0·046	0·023	20	357·30	5·336	R, B
			60·184	0·029	0·022	21	356·80	5·333	R, B
Δ63	8 06·4	42 41	60·171	0·044	0·044	24	80·53	5·574	W, S
			60·184	0·055	0·058	22	80·56	5·582	W, S
h4080	8 15·2	46 49	54·165	0·118	0·110	14	219·58	5·767	S, S
			54·223	0·133	0·122	15	219·73	5·744	W, S
			57·258	0·104	0·100	17	219·42	5·837	R, S
			60·242	0·098	0·069	20	219·70	5·780	R, S
Brs3	8 15·6	44 43	56·226	0·129	0·110	23	327·50	5·212	S, B
			56·272	0·126	0·133	19	327·46	5·194	S, B
h4093	8 22·6	38 44	58·154	0·069	0·042	19	123·32	8·114	S, B
			58·206	0·050	0·042	20	123·17	8·178	R, B
			59·280	0·040	0·032	20	123·08	8·150	S, B
h4109	8 25·1	76 06	59·264	0·061	0·058	23	128·59	26·047	W, B
			60·143	0·058	0·087	21	128·98	26·004	R, B
			60·231	0·038	0·037	20	129·06	25·978	R, B
Cor76	8 39·6	47 52	54·226	0·106	0·133	14	177·18	8·555	R, S
			54·245	0·064	0·133	13	176·88	8·588	S, S
			57·198	0·100	0·115	20	177·71	8·624	W, S
Rmk9	8 42·7	58 21	58·150	±0·054	±0·061	22	291·18	4·140	S, B
			59·150	0·034	0·065	21	291·16	4·124	S, B
			59·195	0·046	0·038	22	290·96	4·142	S, B
h4162	8 56·6	21 37	56·226	0·118	0·122	20	45·13	5·541	S, B
			57·258	0·073	0·065	20	44·19	5·468	R, B
			60·171	0·087	0·061	22	43·41	5·449	S, B
h4166	8 59·2	33 12	58·154	0·054	0·058	22	152·66	13·799	S, B
			59·147	0·042	0·042	21	152·86	13·796	S, B
			60·231	0·031	0·035	20	152·96	13·791	R, B
h4172	9 02·0	25 00	58·269	0·084	0·058	20	219·24	6·818	R, B
			60·171	0·058	0·064	23	219·23	6·794	S, B
h4185	9 06·0	63 38	54·166	0·056	0·087	14	245·04	10·590	S, S
			54·247	0·133	0·068	14	244·44	10·629	R, S
			55·223	0·126	0·110	20	243·84	10·568	S, S

TABLE IV—*continued*

Name	R.A.	Dec. S.	Epoch	m.e.x.	m.e.y.	No.	p.	d.	O, M
	h m	° ′					°	″	
Rmk10	9 16·7	69 23	57·335	0·050	0·046	21	18·40	10·452	S, B
			58·152	0·046	0·065	19	18·14	10·473	S, B
h4224	9 31·7	30 47	57·316	0·100	0·080	20	116·49	7·420	R, B
			58·150	0·130	0·065	20	116·90	7·388	S, B
			61·256	0·094	0·076	20	117·06	7·457	R, B
h4232	9 35·3	57·05	59·269	0·050	0·058	22	302·37	10·870	W, B
			60·231	0·025	0·035	20	302·30	10·920	R, B
			60·324	0·041	0·025	23	302·22	10·871	W, B
h4235	9 37·7	50 42	54·247	0·152	0·102	14	87·22	5·236	R, S
			56·226	0·148	0·102	23	87·72	5·162	S, S
h4249	9 44·5	34 33	56·321	0·126	0·091	20	122·84	4·267	R, B
			56·335	0·079	0·038	21	122·26	4·300	S, B
			58·152	0·054	0·050	23	122·12	4·331	S, B
R132	9 47·0	57 05	54·245	0·087	0·125	14	162·88	7·028	W, S
			56·264	0·118	0·079	16	162·87	7·048	R, S
h4301	10 10·9	65 13	54·226	0·170	0·122	14	25·60	6·862	S, S
			54·280	0·164	0·118	14	25·97	6·878	W, S
			56·272	0·114	0·118	24	25·40	6·785	S, S
			59·360	0·065	0·088	21	25·34	6·864	S, S
Cor103	10 24·3	52·03	57·332	0·088	0·069	20	287·71	5·647	R, B
			58·152	0·107	0·096	24	286·60	5·660	S, B
			59·324	0·119	0·080	22	286·88	5·612	S, B
h4324	10 25·9	46 50	57·324	0·069	0·046	20	244·89	8·270	S, B
			59·155	0·100	0·069	22	245·46	8·310	S, B
Pz	10 27·7	44 33	58·294	0·054	0·058	20	217·88	13·510	S, B
			60·321	0·026	0·043	24	218·34	13·580	S, B
			60·327	0·043	0·029	21	218·30	13·549	S, B
Δ91	10 29·4	71 36	57·199	0·096	0·115	21	60·12	9·986	S, B
			57·256	0·042	0·069	19	59·40	10·003	W, B
			57·316	0·104	0·092	21	60·00	9·988	R, B
Δ97	10 39·4	60 39	55·302	0·110	0·160	20	173·45	12·320	W, S
			55·382	0·106	0·098	21	173·38	12·354	S, S
			58·324	0·100	0·130	20	173·87	12·316	W, S
Cor117	10 45·0	41 03	58·245	0·080	0·058	18	176·50	6·308	R, B
			60·308	0·083	0·048	21	177·78	6·335	R, B
			60·354	0·048	0·058	22	177·48	6·271	S, B
h4399	10 58·3	59 59	56·319	±0·174	±0·156	20	311·44	8·698	W, S
			56·335	0·106	0·114	21	311·20	8·714	S, S
			59·310	0·096	0·088	19	310·28	8·766	S, S
			60·343	0·089	0·090	22	310·46	8·780	W, S
h4412	11 05·2	29·04	57·199	0·107	0·080	20	266·28	12·614	S, B
			57·324	0·080	0·092	21	265·94	12·583	S, B
			57·351	0·088	0·061	22	266·16	12·588	W, B
R165	11 08·5	46 31	55·343	0·064	0·075	23	67·46	3·328	S, S
			55·382	0·102	0·075	21	67·30	3·391	S, S
			59·310	0·058	0·073	20	67·53	3·358	S, S
Brs6	11 23·8	42 07	58·382	0·084	0·069	22	166·80	13·156	W, B
			58·406	0·054	0·058	22	166·41	13·004	W, B
			59·116	0·058	0·073	20	167·24	13·108	W, B

TABLE IV—*continued*

Name	R.A.	Dec. S.	Epoch	m.e.x.	m.e.y.	No.	p.	d.	O, M
	h m	° ′					°	″	
h4446	11 27·2	51 54	59·341	0·069	0·074	22	298·20	10·408	S, S
			59·403	0·084	0·095	20	297·98	10·369	R, S
			60·354	0·098	0·101	21	298·19	10·484	S, S
HIII96	11 27·3	28 43	57·199	0·069	0·069	21	210·40	9·327	S, B
			57·316	0·100	0·107	19	210·34	9·324	R, B
			57·393	0·054	0·042	21	209·85	9·371	S, B
			59·310	0·058	0·061	22	209·72	9·283	S, B
h4460	11 34·4	57 11	54·341	0·087	0·087	14	175·48	8·611	R, S
			55·414	0·110	0·114	20	175·40	8·577	S, S
			57·210	0·115	0·111	20	176·42	8·577	W, S
			58·379	0·092	0·088	24	176·54	8·608	S, S
Hwe70	11 34·5	36 53	57·406	0·073	0·077	21	104·86	3·218	S, S
			59·349	0·054	0·051	21	106·30	3·208	R, B
Δ116	11 51·6	31 43	59·360	0·054	0·065	21	262·06	19·168	S, B
			60·327	0·035	0·031	23	262·06	19·119	S, B
			60·354	0·046	0·031	22	262·18	19·109	S, B
h4481	11 52·2	21 59	57·324	0·088	0·061	21	193·30	3·739	S, S
			57·335	0·073	0·077	16	193·50	3·723	S, S
			59·401	0·069	0·040	22	193·30	3·770	S, S
Cor133	11 54·2	62 13	56·379	0·126	0·156	20	21·18	8·250	R, B
			57·346	0·088	0·096	20	21·38	8·315	W, B
h4487	11 55·2	36 11	57·406	0·065	0·069	21	125·10	5·639	S, B
			59·310	0·050	0·080	19	124·77	5·662	S, B
			59·341	0·050	0·050	21	124·75	5·702	S, B
h4498	12 01·2	65 09	59·338	0·058	0·058	14	59·74	8·790	S, B
			59·365	0·050	0·050	23	59·66	8·810	R, B
			59·368	0·034	0·050	20	59·60	8·811	R, B
h4507	12 07·7	44 20	54·210	0·178	0·145	15	222·40	15·491	R, S
			56·234	0·114	0·133	20	222·02	15·628	R, S
			57·351	0·104	0·111	19	222·04	15·562	W, S
			60·401	0·072	0·084	21	222·18	15·543	W, S
Brs8	12 19·4	57 34	57·412	0·034	0·034	20	334·34	5·294	S, B
			58·360	0·069	0·069	24	334·46	5·360	S, B
			59·349	0·038	0·054	20	334·93	5·332	R, B
h4522	12 19·8	68 55	57·439	0·065	0·119	21	67·06	12·801	S, B
			58·158	0·100	0·054	18	66·28	12·812	S, B
h4540	12 36·8	72 14	59·384	0·130	0·152	21	166·53	11·558	R, S
			59·439	0·109	0·095	20	167·03	11·598	R, S
			59·442	0·069	0·101	22	166·44	11·594	W, S
h4545	12 39·2	74 38	56·434	±0·110	±0·098	24	192·22	9·199	W, B
			56·472	0·145	0·160	21	191·54	9·139	W, B
			57·346	0·126	0·168	21	192·12	9·199	W, B
			57·351	0·142	0·160	20	191·54	9·156	W, B
Δ127	12 53·9	55 22	57·406	0·107	0·115	23	125·67	16·778	S, S
			57·425	0·154	0·096	20	125·92	16·806	R, S
h4563	12 55·6	33 05	57·412	0·069	0·074	20	237·20	6·384	S, B
			58·158	0·104	0·061	18	237·42	6·412	S, B
			59·155	0·058	0·046	20	236·96	6·536	S, B
Cor147	12 57·3	59 04	54·365	0·061	0·046	15	356·04	3·550	S, S
			57·119	0·080	0·088	20	355·76	3·514	R, B

TABLE IV—*continued*

Name	R.A.	Dec. S.	Epoch	m.e.x.	m.e.y.	No.	p.	d.	O. M
	h m	° ′					°	″	
Cor156	13 28·4	60 45	54·453	0·137	0·072	15	171·46	14·611	W, S
			55·341	0·118	0·151	20	171·72	14·623	W, B
HN69	13 31·3	25 59	55·414	0·075	0·068	21	190·24	10·062	S, S
			55·486	0·057	0·075	21	190·62	10·087	S, S
			58·155	0·058	0·073	21	191·06	10·121	S, S
h4608	13 36·6	33 28	55·341	0·038	0·072	20	185·31	4·267	W, B
			55·414	0·042	0·068	21	185·52	4·318	S, B
			58·155	0·031	0·061	20	186·24	4·362	S, B
HIII101	13 46·1	32 30	58·152	0·092	0·092	21	106·62	8·116	S, B
			58·226	0·050	0·034	21	106·47	8·014	W, B
			59·147	0·073	0·058	20	106·74	7·966	S, B
Brs9	13 48·3	50 12	59·499	0·090	0·094	21	76·28	17·599	W, S
			60·401	0·121	0·126	21	76·36	17·629	W, S
			60·434	0·101	0·094	22	76·11	17·616	W, S
h4626	13 49·7	69 50	55·131	0·102	0·118	20	55·69	4·559	R, S
			56·262	0·142	0·160	19	55·23	4·443	S, S
			57·403	0·137	0·087	17	55·88	4·432	W, S
Δ151	13 50·7	55 33	57·428	0·077	0·096	23	47·34	26·422	W, B
			59·384	0·040	0·042	20	48·65	26·900	R, B
			59·439	0·077	0·055	22	48·60	27·167	R, B
h4647	14 01·1	47 50	60·163	0·069	0·077	22	294·68	10·968	S, S
			60·434	0·081	0·073	21	294·94	10·936	W, S
			60·477	0·074	0·066	20	295·06	10·960	R, S
h4661	14 06·3	28 25	54·182	0·220	0·122	15	230·24	4·381	W, S
			57·423	0·154	0·107	20	229·99	4·490	W, S
			60·513	0·069	0·052	20	230·41	4·548	R, B
Δ159	14 15·4	58 00	57·428	0·092	0·092	21	158·77	9·210	W, S
			58·464	0·073	0·065	24	158·88	9·191	W, S
			58·516	0·080	0·073	21	158·57	9·184	W, S
Gls204	14 17·9	67 02	56·314	0·098	0·060	21	324·22	12·476	S, B
			59·442	0·077	0·061	23	324·30	12·398	W, B
h4683	14 26·7	62 50	54·373	0·098	0·126	15	61·85	13·142	R, S
			60·163	0·093	0·086	21	62·10	13·275	S, S
			60·513	0·097	0·077	20	62·16	13·324	R, S
Hwe75	14 31·0	37 06	57·161	0·104	0·107	20	214·98	4·118	W, B
			57·502	0·054	0·042	23	215·36	4·178	S, B
h4706	14 44·6	47 00	55·486	0·080	0·065	20	219·84	6·651	S, B
			56·570	0·064	0·083	20	219·38	6·719	S, B
h4727	14 57·6	27 27	54·226	0·083	0·110	14	38·56	7·424	S, S
			55·565	0·075	0·106	21	38·80	7·505	S, S
Cor178	15 03·8	40 38	58·207	±0·077	±0·058	20	75·64	4·946	S, B
			60·163	0·053	0·051	22	75·62	4·922	S, B
h4743	15 05·8	32 27	54·172	0·141	0·160	13	196·54	11·059	S, S
			54·191	0·166	0·102	14	196·56	11·094	W, S
Cor179	15 06·7	36 52	54·202	0·110	0·087	14	227·94	6·572	R, S
			54·221	0·110	0·182	14	227·46	6·586	S, S
			56·549	0·091	0·106	21	228·24	6·453	W, S
			57·565	0·073	0·054	17	227·39	6·458	S, S

TABLE IV—*continued*

Name	R.A.	Dec. S.	Epoch	m.e.x.	m.e.y.	No.	p.	d.	O, M
	h m	° ′					°	″	
Δ187	15 26·5	47 12	54·210	0·148	0·160	14	224·58	26·261	R, S
			54·226	0·224	0·133	14	224·64	26·261	S, S
Pz	15 50·5	33 40	57·199	0·084	0·061	23	49·36	10·325	S, B
			59·265	0·033	0·054	26	49·39	10·395	S, B
			59·579	0·064	0·033	22	49·48	10·410	S, B
Hwe81	15 54·0	35 48	54·224	0·189	0·099	14	102·21	6·602	S, S
			54·570	0·110	0·122	14	102·36	6·595	S, S
Brs11	16 03·2	32 23	57·369	0·065	0·061	20	83·34	7·669	S, B
			59·598	0·050	0·050	21	84·32	7·784	S, B
			60·229	0·054	0·045	22	84·00	7·749	S, B
h4837	16 05·4	43 23	54·265	0·125	0·141	14	74·22	8·940	R, S
			54·377	0·152	0·129	14	73·43	8·911	R, S
			60·280	0·106	0·089	20	74·10	9·064	S, S
h4840	16 10·9	34 34	54·224	0·129	0·087	14	298·81	4·957	S, S
			56·235	0·126	0·080	20	298·80	4·931	R, S
HV134	16 14·2	19 49	55·245	0·129	0·106	21	333·17	46·783	R, S
			56·262	0·126	0·079	21	333·04	46·640	S, S
HV124	16 14·7	19 53	55·245	0·079	0·072	21	19·84	12·765	R, S
			56·262	0·072	0·068	20	20·80	12·744	S, S
			58·598	0·100	0·065	22	20·52	12·698	W, S
h4848	16 17·5	32 58	54·227	0·137	0·129	14	152·88	6·196	S, S
			54·570	0·068	0·072	15	152·86	6·207	S, S
			57·565	0·061	0·077	19	153·16	6·235	S, S
			60·242	0·041	0·037	22	153·30	6·262	W, B
HN39	16 18·4	29 28	55·243	0·060	0·072	18	353·75	5·394	R, S
			56·565	0·065	0·084	21	354·60	5·313	S, S
			58·270	0·069	0·054	20	354·38	5·378	S, S
Cor206	16 55·2	50 01	54·557	0·106	0·068	14	232·93	7·894	S, S
			55·237	0·079	0·050	20	233·32	7·909	R, S
			57·369	0·080	0·077	21	233·54	7·878	S, S
h4916	17 00·9	49 20	58·636	0·092	0·069	21	275·62	9·949	W, B
			59·579	0·073	0·055	22	275·88	9·972	S, B
h4921	17 02·9	31 33	60·590	0·074	0·055	24	145·71	8·794	S, B
			60·625	0·063	0·066	21	145·96	8·758	W, B
Δ213	17 02·9	46 37	55·606	0·072	0·075	20	166·44	8·199	R, S
			55·650	0·075	0·083	20	166·14	8·151	S, S
			56·549	0·096	0·096	20	166·27	8·135	W, S
h589	17 04·7	24 49	54·279	0·087	0·106	14	300·68	9·975	S, S
			55·284	0·133	0·133	20	300·12	10·001	W, S
Sh243	17 09·2	26 27	54·570	±0·069	±0·067	17	165·68	4·314	S, S
			54·625	0·063	0·068	14	165·50	4·290	W, S
			56·262	0·064	0·060	19	164·77	4·365	S, S
			56·570	0·098	0·083	21	165·24	4·412	S, S
			57·584	0·092	0·065	21	164·68	4·404	S, S
HIII25	17 11·9	24 11	58·551	0·054	0·046	21	354·08	10·356	S, B
			59·262	0·042	0·046	25	354·35	10·370	S, B
			59·631	0·053	0·027	24	354·90	10·428	S, B
Cor221	17 43·0	31 58	55·628	0·160	0·156	20	308·52	9·346	R, B
			55·658	0·133	0·133	23	308·33	9·394	S, B

TABLE IV—*continued*

Name	R.A.	Dec. S.	Epoch	m.e.x.	m.e.y.	No.	p.	d.	O, M
	h m	° ′					°	″	
Pz	17 44·8	30 32	56·311	0·088	0·096	20	188·92	9·992	S, S
			56·675	0·094	0·079	22	189·12	10·047	S, S
h5023	18 03·8	40 27	54·631	0·133	0·118	16	276·56	8·725	W, S
			55·284	0·133	0·118	21	276·37	8·672	W, S
			55·303	0·143	0·145	20	276·26	8·757	S, B
Δ222	18 26·5	38 48	58·341	0·034	0·058	21	358·68	21·364	S, B
			58·636	0·027	0·065	21	358·62	21·380	W, B
			58·694	0·050	0·058	20	358·80	21·364	W, B
Brs14	18 54·3	37 12	55·300	0·075	0·060	21	281·07	12·794	S, B
			55·650	0·145	0·166	21	280·94	12·822	S, B
			56·320	0·098	0·110	19	281·20	12·790	S, B
			58·677	0·061	0·065	20	280·86	12·800	S, B
h5094	19 06·2	34 01	54·631	0·068	0·083	20	191·47	22·872	W, S
			56·675	0·087	0·083	16	190·95	23·318	S, S
			58·325	0·084	0·077	20	190·84	23·474	R, S
			58·688	0·061	0·054	21	190·66	23·486	W, S
h5092	19 06·5	47 32	54·650	0·087	0·083	16	350·88	17·874	W, S
			56·377	0·126	0·110	20	351·08	17·844	S, S
			56·680	0·122	0·126	21	350·86	17·811	S, S
h5117	19 21·2	44 05	55·683	0·126	0·137	16	260·66	5·856	R, B
			57·601	0·126	0·104	20	259·90	5·779	S, B
			59·694	0·058	0·052	20	260·34	5·935	S, B
h5151	19 44·5	37 09	54·377	0·205	0·156	14	357·47	7·774	R, S
			54·459	0·137	0·110	15	357·36	7·753	S, S
Rmk25	20 06·9	57 16	56·374	0·122	0·114	20	28·66	7·474	S, S
			56·680	0·079	0·091	24	28·26	7·446	S, S
			58·688	0·088	0·080	20	28·94	7·411	W, S
Δ230	20 11·1	40 30	56·377	0·133	0·098	21	116·44	9·851	S, B
			56·639	0·118	0·098	23	116·80	9·760	S, B
			59·740	0·029	0·035	21	116·80	9·814	S, B
			60·664	0·060	0·063	21	116·70	9·728	W, B
h5223	20 43·9	56 46	56·680	0·110	0·087	24	289·62	9·021	S, B
			57·429	0·138	0·119	21	289·72	9·117	S, B
			58·653	0·096	0·077	24	289·85	9·138	S, B
h5246	21 03·1	54 59	55·737	0·091	0·075	20	129·10	3·549	S, S
			56·473	0·068	0·054	19	128·99	3·575	R, S
			56·792	0·107	0·080	21	127·90	3·554	W, S
			57·716	0·042	0·038	21	128·60	3·677	W, S
h5251	21 05·8	23 31	55·759	0·126	0·106	20	304·02	8·758	R, S
			56·429	0·114	0·170	20	304·50	8·719	S, S
			58·748	0·088	0·119	20	304·42	8·762	S, S
h5261	21 28·5	86 18	56·732	0·084	0·058	20	196·00	4·872	R, B
			60·768	0·073	0·134	20	196·46	5·066	S, B
h5288	21 36·4	38 23	55·514	±0·083	±0·122	20	59·96	19·904	S, B
			55·759	0·133	0·110	19	59·90	19·897	R, B
			58·653	0·073	0·084	20	60·38	19·941	S, B
h5325	22 15·4	73 18	56·484	0·137	0·106	20	267·15	18·959	S, B
			60·781	0·051	0·062	21	267·26	18·858	S, B
			60·833	0·031	0·040	20	267·61	18·962	S, B

TABLE IV—*continued*

Name	R.A.	Dec. S.	Epoch	m.e.x.	m.e.y.	No.	p.	d.	O, M
	h m	° ′					°	″	
Jc19	22 18·7	41 57	55·514	0·160	0·091	20	73·69	24·498	S, B
			58·806	0·065	0·077	19	73·30	24·120	S, B
			59·809	0·051	0·052	21	73·23	23·928	S, B
Cor251	22 21·4	40 57	59·765	0·092	0·086	22	183·90	6·492	S, S
			59·844	0·117	0·082	21	184·10	6·490	W, S
h5366	22 46·8	43 19	59·817	0·080	0·075	22	251·54	14·896	S, S
			60·680	0·071	0·074	22	251·75	14·856	S, B
			60·852	0·063	0·048	19	251·58	14·802	S, B
h5371	22 52·3	26 38	55·514	0·166	0·166	20	343·54	9·038	S, B
			60·852	0·052	0·031	24	343·95	9·192	S, B
h5382	22 59·2	51 54	60·781	0·061	0·091	19	51·32	7·670	S, S
			60·861	0·083	0·079	21	51·12	7·673	R, S
Δ246	23 01·5	51 14	53·768	0·079	0·076	14	255·97	8·494	W, S
			54·489	0·087	0·110	14	255·67	8·478	R, S
			55·506	0·064	0·064	20	256·35	8·528	S, S
			55·833	0·075	0·083	21	255·98	8·587	S, S
h3184	23 15·7	19 05	58·877	0·058	0·087	22	284·29	5·424	R, B
			60·852	0·071	0·066	26	284·17	5·246	S, B
HII24	23 40·8	19 14	55·852	0·091	0·064	20	135·50	6·503	S, B
			56·549	0·137	0·133	21	135·32	6·566	S, B
			58·538	0·065	0·077	20	135·92	6·586	S, B
			60·681	0·052	0·049	22	135·70	6·630	S, B
Cor261	23 42·2	61 04	58·877	0·079	0·041	20	100·54	5·661	R, B
			59·844	0·051	0·047	22	100·76	5·726	W, B
			60·861	0·052	0·044	20	101·10	5·670	R, B
Δ253	23 49·2	27 36	55·888	0·094	0·046	23	270·22	6·588	S, B
			56·550	0·156	0·087	20	270·10	6·521	S, B
Arg46	23 54·4	27 05	53·806	0·128	0·104	13	169·18	10·607	S, S
			53·818	0·079	0·083	14	168·98	10·574	W, S

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Minor Planets Observed at Sydney Observatory during 1964

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The following observations of minor planets were made photographically at Sydney Observatory with the 9-inch Taylor, Taylor and Hobson lens. Observations were confined to those with southern declinations in the *Ephemerides of Minor Planets* published by the Institute of Theoretical Astronomy at Leningrad.

On each plate two exposures, separated in declination by approximately 0′·5, were taken with an interval of about 20 minutes between them. The beginnings and endings of the exposures were automatically recorded on a chronograph by a contact on the shutter.

Rectangular coordinates of both images of the minor planet and three reference stars were measured in direct and reversed positions of the plate on a long screw measuring machine. The usual three star dependence reduction retaining second order terms in the differences of the equatorial coordinates was used. Proper motions, when they were available, were applied to bring the star positions to the epoch of the plate. Each exposure was reduced separately in order to provide a check by comparing the difference between the two positions with the motion derived from the ephemeris. The tabulated results are means of the two positions at the average time except in cases **1760**, 1774 where each result is from only one image owing to a failure in timing the other exposure. No correction has been applied for aberration, light time or parallax but in Table I are given the factors which give the parallax correction when divided by the distance. The serial numbers follow on from those of a previous paper (Robertson, 1965). The observers named in Table II are W. H. Robertson (R), K. P. Sims (S) and H. W. Wood (W). The measurements were made by Mrs. J. Brannigan and Miss E. Hardaker who have also assisted in the computation.

Reference

Robertson, W. H., 1965. *J. Roy. Soc. N.S.W.*, **97**, 177. *Sydney Observatory Papers*, No. 49.

Table I

No.	Planet	U.T.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″
1677	12	1964	July	27·64473	21	46	44·18	+04	58	59·2	+0·02	—5·5
1678	12	1964	Aug.	20·54849	21	29	16·36	+04	22	11·5	—0·04	—5·4
1679	16	1964	July	21·62872	20	49	04·17	—15	43	38·8	+0·04	—2·7
1680	16	1964	July	27·61680	20	44	19·73	—16	07	52·8	+0·06	—2·7
1681	22	1964	May	21·58388	15	31	35·47	—15	26	32·0	+0·07	—2·6
1682	36	1964	July	30·63940	20	52	46·50	—42	32	53·4	+0·18	+1·1
1683	54	1964	March	19·53401	10	56	32·66	—05	06	10·4	—0·03	—4·2
1684	54	1964	March	23·53601	10	53	03·07	—04	51	58·2	+0·02	—4·2
1685	65	1964	July	21·62872	20	47	47·94	—15	12	24·6	+0·04	—2·8
1686	65	1964	July	27·61680	20	43	32·19	—15	34	13·1	+0·07	—2·8
1687	92	1964	July	07·67552	20	52	40·31	—22	38	08·8	+0·06	—1·7
1688	92	1964	July	22·62221	20	42	38·42	—24	08	34·1	+0·04	—1·5
1689	106	1964	Sept.	17·57990	23	43	54·50	—09	13	05·0	0·00	—3·7
1690	106	1964	Sept.	29·54595	23	34	53·86	—09	56	17·6	+0·02	—3·6
1691	112	1964	May	21·53013	14	23	44·72	—18	44	08·1	+0·05	—2·3
1692	118	1964	May	04·66296	16	18	50·59	—23	47	59·9	+0·07	—1·5
1693	122	1964	July	29·59618	20	21	59·30	—17	29	42·5	+0·07	—2·5
1694	130	1964	Aug.	20·58472	22	37	27·99	—13	51	31·8	+0·08	—3·0
1695	130	1964	Sept.	15·50125	22	21	13·60	—19	39	24·7	—0·09	—1·8
1696	131	1964	May	04·66296	16	31	42·46	—20	50	22·5	+0·04	—2·0
1697	131	1964	May	18·63862	16	19	22·70	—20	59	10·8	+0·11	—2·0
1698	154	1964	July	08·53229	17	29	47·61	—48	29	00·7	+0·08	—2·2
1699	174	1964	Sept.	17·55300	22	33	35·88	—03	17	05·8	+0·07	—4·5

Table I—*continued*

No.	Planet	U.T.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″
1700	174	1964	Sept.	24·49999	22	28	22·74	—03	26	29·8	—0·02	—4·4
1701	200	1964	April	23·63024	15	10	03·05	—28	02	16·6	+0·02	—0·9
1702	200	1964	May	19·54410	14	46	24·22	—26	42	08·9	+0·02	—1·1
1703	202	1964	June	29·61138	18	23	23·53	—14	57	50·7	+0·11	—2·9
1704	202	1964	July	06·57276	18	17	50·17	—15	14	12·0	+0·06	—2·8
1705	206	1964	May	21·64800	17	23	07·34	—17	45	23·8	+0·03	—2·4
1706	206	1964	June	29·51116	16	50	09·77	—17	21	55·8	0·00	—2·5
1707	210	1964	Sept.	17·57990	23	39	03·80	—08	26	29·0	+0·01	—3·8
1708	210	1964	Sept.	29·54595	23	28	47·11	—09	02	18·8	+0·03	—3·7
1709	216	1964	March	17·60974	12	55	35·09	—13	54	23·6	—0·07	—3·0
1710	216	1964	April	01·60186	12	44	35·37	—12	16	02·4	+0·06	—3·2
1711	224	1964	April	07·68198	14	57	10·84	—23	25	40·0	+0·08	—1·6
1712	224	1964	May	13·54550	14	25	32·06	—22	29	18·1	+0·02	—1·7
1713	234	1964	July	21·56948	19	32	22·29	—05	52	53·8	+0·02	—4·1
1714	234	1964	Aug.	06·51314	19	21	08·36	—10	04	56·9	0·00	—3·5
1715	242	1964	April	07·61963	13	37	04·96	—11	27	03·5	+0·05	—3·3
1716	259	1964	July	07·59718	18	34	38·08	—26	58	51·8	+0·12	—1·1
1717	261	1964	Sept.	17·57990	23	30	59·81	—09	27	02·5	+0·03	—3·6
1718	261	1964	Sept.	29·54595	23	20	20·77	—10	30	36·8	+0·05	—3·5
1719	264	1964	April	13·65930	15	04	26·34	—14	49	18·9	+0·04	—2·8
1720	264	1964	May	18·54330	14	34	22·11	—14	05	16·4	+0·04	—3·0
1721	306	1964	April	23·66294	15	43	36·16	—06	53	52·3	+0·05	—4·0
1722	306	1964	May	21·55964	15	19	17·80	—04	42	37·2	+0·02	—4·3
1723	308	1964	March	19·68305	12	54	05·96	—04	53	45·2	+0·17	—4·3
1724	308	1964	April	02·59288	12	43	30·36	—03	23	18·3	+0·04	—4·4
1725	312	1964	March	18·66974	13	05	40·55	—08	02	39·3	+0·10	—3·8
1726	312	1964	April	01·63012	12	53	26·05	—07	44	19·8	+0·12	—3·9
1727	312	1964	April	07·58864	12	47	45·24	—07	33	07·5	+0·06	—3·9
1728	322	1964	May	19·58710	15	36	55·13	—22	37	45·1	+0·05	—1·7
1729	323	1964	July	21·59864	20	11	38·14	—37	08	56·3	+0·03	+0·5
1730	323	1964	Aug.	06·54112	19	51	30·80	—41	23	20·5	+0·03	+1·2
1731	324	1964	May	20·61502	16	27	56·60	—38	34	07·3	+0·04	+0·7
1732	324	1964	June	24·50508	15	50	17·60	—36	27	20·1	+0·08	+0·4
1733	337	1964	April	28·55173	12	48	50·32	—12	08	36·5	+0·12	—3·3
1734	356	1964	July	22·64878	21	01	11·76	—26	38	42·5	+0·09	—1·1
1735	362	1964	May	21·61264	15	55	13·84	—27	49	19·8	+0·11	—1·0
1736	362	1964	June	01·54472	15	43	50·43	—27	39	55·4	+0·01	—0·9
1737	372	1964	May	13·62030	15	52	09·30	—52	18	31·8	+0·11	+2·8
1738	372	1964	June	04·53068	15	28	01·78	—51	12	58·6	+0·04	+2·6
1739	375	1964	June	24·63422	19	18	18·01	—42	32	46·2	+0·03	+1·3
1740	384	1964	May	04·62611	15	29	45·56	—19	28	35·3	+0·06	—2·2
1741	387	1964	Nov.	03·63866	03	33	18·62	—08	04	37·3	+0·09	—3·8
1742	387	1964	Dec.	03·47956	03	07	49·82	—08	12	47·8	—0·09	—3·8
1743	409	1964	June	23·66092	19	44	58·46	—08	05	21·2	+0·04	—3·8
1744	409	1964	July	21·54576	19	20	04·64	—07	07	04·0	—0·03	—3·9
1745	420	1964	May	04·66296	16	29	19·36	—22	11	35·8	+0·05	—1·8
1746	420	1964	May	18·63862	16	19	53·72	—21	30	50·2	+0·11	—1·9
1747	426	1964	March	19·56639	11	31	02·57	—23	26	37·7	—0·01	—1·6
1748	426	1964	April	01·55140	11	18	20·90	—23	03	49·4	+0·09	—1·7
1749	454	1964	April	02·62660	13	56	45·66	—10	05	31·1	—0·01	—3·5
1750	454	1964	April	30·55977	13	31	24·69	—09	19	35·3	+0·07	—3·6
1751	469	1964	May	13·65734	16	54	15·66	—40	11	08·0	+0·06	+1·0
1752	469	1964	May	20·64352	16	47	59·32	—40	16	05·1	+0·10	+0·9
1753	503	1964	Oct.	01·54925	23	56	07·90	—08	19	46·9	0·00	—3·8
1754	503	1964	Oct.	09·50652	23	49	43·71	—08	48	25·6	—0·05	—3·7
1755	505	1964	Aug.	12·66756	22	35	24·80	—23	07	50·5	+0·13	—1·7
1756	505	1964	Sept.	17·52370	22	04	52·34	—26	41	30·6	+0·05	—1·1
1757	536	1964	July	30·67406	21	37	57·55	—42	06	55·1	+0·20	+1·1
1758	536	1964	Sept.	01·51909	21	10	32·55	—43	31	27·4	+0·02	+1·5
1759	554	1964	March	23·59372	12	09	02·93	—05	53	00·6	+0·03	—4·1
1760	554	1964	April	06·58394	11	56	16·16	—04	31	05·3	+0·14	—4·3
1761	559	1964	July	08·64956	20	40	38·56	—20	16	11·8	+0·01	—2·0
1762	559	1964	Aug.	12·52476	20	11	51·79	—24	01	08·5	—0·02	—1·5
1763	606	1964	July	22·67520	21	29	15·44	—17	07	04·4	+0·11	—2·6

TABLE I—*continued*

No.	Planet	U.T.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″
1764	606	1964	Sept.	03·49395	20	49	13·47	—16	19	21·0	—0·01	—2·6
1765	639	1964	June	01·57348	16	26	22·34	—28	23	17·3	+0·01	—0·8
1766	654	1964	March	17·58046	12	14	57·56	—39	27	11·8	—0·09	+0·8
1767	654	1964	April	01·57708	11	58	58·12	—38	29	02·9	+0·10	+0·7
1768	670	1964	July	08·60346	19	31	32·69	—10	32	28·4	+0·02	—3·5
1769	670	1964	Aug.	05·51544	19	09	00·74	—12	16	45·4	+0·03	—3·2
1770	690	1964	June	02·67343	18	52	25·76	—17	27	01·2	+0·01	—2·5
1771	690	1964	July	08·56610	18	24	47·99	—15	53	40·7	+0·05	—2·7
1772	695	1964	April	08·55937	12	22	14·56	—25	03	40·1	+0·03	—1·3
1773	714	1964	June	02·64430	18	02	03·72	—12	09	26·9	+0·03	—3·2
1774	714	1964	July	07·56372	17	30	30·74	—09	37	03·7	+0·14	—3·6
1775	736	1964	Sept.	17·57990	23	40	31·28	—08	29	04·8	+0·01	—3·8
1776	736	1964	Sept.	29·54595	23	31	32·43	—09	55	08·2	+0·03	—3·6
1777	746	1964	Aug.	05·59230	20	30	59·32	—44	40	57·4	+0·13	+1·6
1778	772	1964	Nov.	03·59492	02	24	21·09	—08	40	12·4	+0·10	—3·8
1779	772	1964	Nov.	23·46200	02	06	38·53	—07	22	16·2	—0·10	—3·9
1780	773	1964	March	23·63864	13	35	42·19	—32	56	23·6	—0·02	—0·1
1781	773	1964	April	09·58578	13	20	07·06	—33	24	07·9	0·00	0·0
1782	791	1964	July	21·62872	20	56	40·04	—15	43	41·9	+0·02	—2·7
1783	791	1964	July	27·61680	20	52	37·86	—16	43	24·6	+0·05	—2·6
1784	791	1964	Aug.	12·56496	20	41	08·42	—19	25	34·0	+0·05	—2·2
1785	796	1964	April	09·61945	13	42	56·08	—05	52	23·8	+0·05	—4·1
1786	798	1964	May	13·58025	15	09	11·20	—13	46	24·4	+0·04	—3·0
1787	804	1964	June	04·68497	19	16	46·70	—45	17	16·8	+0·02	+1·8
1788	804	1964	July	06·60622	18	44	15·96	—46	14	50·7	+0·16	+1·4
1789	818	1964	Aug.	11·63125	21	52	45·34	—35	56	31·8	+0·11	+0·3
1790	818	1964	Sept.	08·52928	21	30	25·85	—37	13	06·5	+0·07	+0·5
1791	850	1964	Aug.	04·64363	21	51	16·53	—20	48	03·0	+0·07	—2·0
1792	905	1964	Sept.	29·54595	23	31	41·53	—10	35	42·8	+0·03	—3·5
1793	924	1964	Aug.	12·63723	21	54	34·79	—10	56	56·8	+0·11	—3·4
1794	924	1964	Sept.	01·55040	21	40	20·49	—13	32	12·3	+0·04	—3·0
1795	936	1964	July	08·64956	20	36	22·36	—21	50	29·8	+0·02	—1·8
1796	936	1964	Aug.	12·52476	20	09	45·07	—23	37	10·7	—0·01	—1·6
1797	984	1964	July	07·67552	20	50	11·91	—21	42	07·9	+0·07	—1·9
1798	984	1964	Aug.	11·58910	20	17	53·10	—21	18	14·4	+0·03	—1·9
1799	1093	1964	June	01·60922	17	25	32·88	—39	44	14·5	—0·01	+0·9
1800	1093	1964	June	29·54571	16	50	10·57	—43	56	16·1	+0·18	+1·4
1801	1095	1964	Oct.	01·58221	00	19	17·23	—13	08	21·2	+0·05	—3·1
1802	1102	1964	June	04·60590	17	27	12·83	—07	02	28·5	0·00	—3·9
1803	1132	1964	June	29·64756	19	49	14·94	—35	28	00·2	+0·05	+0·3
1804	1132	1964	July	06·65229	19	44	04·27	—36	04	20·4	+0·15	+0·2
1805	1244	1964	March	19·61647	12	52	11·14	—22	39	34·4	—0·03	—1·7
1806	1244	1964	April	08·59529	12	33	56·72	—21	09	10·4	+0·12	—2·0
1807	1334	1964	Aug.	12·60346	21	33	37·25	—16	42	56·8	+0·05	—2·6
1808	784	1964	July	07·63966	20	14	01·18	—40	57	21·6	+0·04	+1·1
1809	784	1964	July	27·58756	19	53	51·16	—41	19	19·5	+0·11	+1·1
1810	784	1964	Aug.	05·55440	19	45	43·97	—40	58	02·8	+0·09	+1·1
1811	784	1964	Aug.	11·54947	19	41	17·74	—40	34	10·8	+0·15	+0·9

TABLE II

No.	Comparison Stars	Dependences			
1677	Yale *20* 7607, 7611, 7630	0·41844	0·27164	0·30992	W
1678	Yale *20* 7525, 7529, 7542	0·34113	0·48394	0·17494	S
1679	Yale *12* I 7846, 7862, 7870	0·62281	0·19430	0·18289	S
1680	Yale *12* I 7813, 7827, 7828	0·25141	0·45676	0·29183	W

TABLE II—*continued*

No.	Comparison Stars	Dependences			
1681	Yale *12* I 5695, 5705, 5713	0·34357	0·21797	0·43846	W
1682	Cord. D. 15076, 15106, Cape Z. 19122	0·44328	0·23598	0·32074	W
1683	Yale *17* 4180, 4184, 4192	0·40212	0·30458	0·29330	W
1684	Yale *17* 4160, 4163, 4182	0·31834	0·22332	0·45834	R
1685	Yale *12* I 7842, 7847, 7853	0·15794	0·52185	0·32021	S
1686	Yale *12* I 7801, 7817, 7827	0·19555	0·30592	0·49852	W
1687	Yale *14* 14488, 14496, 14524	0·42390	0·32803	0·24807	W
1688	Yale *14* 14366, 14397, 14420	0·16065	0·55127	0·28808	S
1689	Yale *16* 8391, 8394, 8405	0·20528	0·55355	0·24117	S
1690	Yale *11* 8229, 8240, *16* 8363	0·43028	0·38167	0·18805	R
1691	Yale *12* II 6019, 6038, *12* I 5364	0·34347	0·30667	0·34986	W
1692	Yale *14* 11437, 11451, 11462	0·43083	0·33155	0·23762	R
1693	Yale *12* I 7671, 7677, 7695	0·48581	0·30749	0·20670	W
1694	Yale *12* I 8426, 8431, 8446	0·35991	0·32945	0·31064	S
1695	Yale *13* I 9491, 9499, *12* II 9500	0·41112	0·45278	0·13611	R
1696	Yale *13* I 6785, 6789, 6804	0·20279	0·44954	0·34767	R
1697	Yale *13* I 6739, 6767, *12* II 6753	0·31330	0·40193	0·28477	W
1698	Cape Ft. 16751, 16820, 16953	0·42762	0·28184	0·29054	W
1699	Yale *17* 7838, 7839, 7853	0·17549	0·39583	0·42868	S
1700	Yale *17* 7814, 7822, 7827	0·51924	0·08254	0·39822	S
1701	Yale *13* II 9543, 9566, 9577	0·31728	0·42730	0·25542	S
1702	Yale *14* 10617, 10647, 10653	0·37831	0·27694	0·34475	W
1703	Yale *12* I 6740, 6745, 6768	0·24536	0·45188	0·30276	S
1704	Yale *12* I 6673, 6685, 6725	0·24926	0·52122	0·22953	W
1705	Yale *12* I 6235, 6249, 6258	0·40526	0·40493	0·18981	W
1706	Yale *12* I 6035, 6046, 6066	0·54236	0·26200	0·19564	S
1707	Yale *16* 8368, 8372, 8390	0·47654	0·34559	0·17787	S
1708	Yale *16* 8330, 8338, 8341	0·38919	0·24828	0·36253	R
1709	Yale *11* 4648, 4657, 4668	0·23937	0·39767	0·36296	W
1710	Yale *11* 4607, 4609, 4621	0·34139	0·28982	0·36879	S
1711	Yale *14* 10727, 10747, 10758	0·44598	0·21516	0·33886	W
1712	Yale *14* 10417, 10455, 10468	0·38993	0·16410	0·44597	S
1713	Yale *16* 6805, 6828, 6830	0·25416	0·24354	0·50230	S
1714	Yale *11* 6761, 6769, 6775	0·28873	0·38255	0·32872	R
1715	Yale *11* 4834, 4859, 4860	0·29000	0·25861	0·45139	S
1716	Yale *13* II 12091, *14* 12932, 12944	0·56755	0·52059	—0·08814	W
1717	Yale *11* 8217, 8238, *16* 8348	0·75533	—0·01759	0·26226	S
1718	Yale *11* 8170, 8177, 8182	0·46687	0·40885	0·12428	R
1719	Yale *12* I 5554, 5573, 5581	0·25594	0·51098	0·23308	R
1720	Yale *11* 5117, 5121, 5139	0·28709	0·26601	0·44690	W
1721	Yale *16* 5489, 5493, 5509	0·20461	0·38136	0·41403	S
1722	Yale *17* 5353, 5368, 5375	0·29359	0·43558	0·27084	W
1723	Yale *17* 4705, 4716, 4717	0·12157	0·53553	0·34291	W
1724	Yale *17* 4664, 4675, 4683	0·32936	0·40855	0·26209	S
1725	Yale *16* 4724, 4733, 4737	0·73017	0·98017	—0·71034	W
1726	Yale *16* 4672, 4680, 4681	0·16921	0·30951	0·52128	S
1727	Yale *16* 4642, 4646, 4666	0·50651	0·18551	0·30798	W
1728	Yale *14* 11066, 11079, 11095	0·42765	0·40011	0·17223	W
1729	Cape *18* 10484, 10516, 10522	0·52977	0·25007	0·22016	S
1730	Cord. D. 14517, 14549, 14551	0·67183	0·09118	0·23699	R
1731	Cape *18* 8139, 8165, 8175	0·44730	0·28338	0·26932	W
1732	Cape *18* 7831, 7838, 7869	0·43095	0·17466	0·39439	R
1733	Yale *11* 4616, 4631, 4643	0·31834	0·41982	0·26185	W
1734	Yale *13* II 13833, 13880, *14* 14575	0·22914	0·09111	0·67975	S
1735	Yale *13* II 9990, 10016, 10038	0·26929	0·41567	0·31504	W
1736	Yale *13* II 9873, 9895, 9916	0·49367	0·33466	0·17167	R
1737	Cape *19* 6098, 6117, 6153	0·35788	0·35651	0·28561	S
1738	LPl F 3201, 3214, 3229	0·54816	0·15166	0·30018	R
1739	Cord. D. 14194, 14215, 14233	0·40343	0·30204	0·29453	R
1740	Yale *12* II 6400, 6425, 6431	0·35294	0·27824	0·36882	R
1741	Yale *16* 833, 843, 861	0·26174	0·24071	0·49754	R
1742	Yale *16* 715, 719, 737	0·25042	0·49634	0·25324	R
1743	Yale *16* 6925, 6926, 6932	0·54516	0·19112	0·26372	R
1744	Yale *16* 6699, 6702, 6727	0·30624	0·30381	0·38995	S
1745	Yale *14* 11498, 11519, *13* I 6782	0·37709	0·39124	0·23166	R
1746	Yale *13* I 6754, 6759, 6767	0·35068	0·50823	0·14108	W

TABLE II—*continued*

No.	Comparison Stars	Dependences			
1747	Yale *14* 8877, 8880, 8890	0·41825	0·30886	0·27289	W
1748	Yale *14* 8748, 8753, 8789	0·43017	0·25910	0·31073	S
1749	Yale *16* 4957, 4968, 4973	0·26024	0·27127	0·46849	S
1750	Yale *16* 4828, 4829, 4848	0·15134	0·43458	0·41408	W
1751	Cord. D. 11954, 11955, 11991	0·27249	0·41620	0·31130	S
1752	Cord. D. 11780, 11843, Cape *18* 8330	0·29407	0·42105	0·28488	W
1753	Yale *16* 8433, 8440, 8449	0·31594	0·45213	0·23193	S
1754	Yale *16* 8408, 8419, 8429	0·34417	0·26801	0·38782	R
1755	Yale *14* 15304, 15315, 15316	0·28167	0·43656	0·28176	S
1756	Yale *13* II 14379, 14409, *14* 15082	0·19357	0·48913	0·31730	S
1757	Cord. D. 15469, 15534, 15545	0·29470	0·25757	0·44773	W
1758	Cord. D. 15239, 15280, 15296	0·26101	0·28050	0·45849	R
1759	Yale *17* 4510, 4524, 4535	0·42694	0·27867	0·29439	R
1760	Yale *17* 4455, 4457, 4468	0·33743	0·22664	0·43593	W
1761	Yale *13* I 8853, 8888, 8912	0·30187	0·34097	0·35716	W
1762	Yale *14* 14025, 14065, 14067	0·19289	0·47368	0·33343	S
1763	Yale *12* I 8088, 8096, 8113	0·32788	0·31457	0·35755	S
1764	Yale *12* I 7845, 7846, 7871	0·38785	0·25705	0·35510	S
1765	Yale *13* II 10283, 10308, 10339	0·25845	0·30870	0·43285	R
1766	Cape *18* 5784, 5785, 5812	0·45563	0·36375	0·18062	W
1767	Cape *18* 5651, 5656, 5674	0·15982	0·43986	0·40032	S
1768	Yale *11* 6844, 6868, 6873	0·41008	0·23747	0·35244	W
1769	Yale *11* 6648, 6653, 6662	0·48747	0·22619	0·28634	R
1770	Yale *12* I 6981, 6984, 7003	0·35911	0·38411	0·25678	R
1771	Yale *12* I 6749, 6775, 6782	0·48870	0·28788	0·22342	W
1772	Yale *14* 9350, 9378, 9384	0·41659	0·24137	0·34203	W
1773	Yale *11* 6148, 6152, 6170	0·19756	0·33448	0·46796	R
1774	Yale *16* 5933, 5934, 5952	0·34603	0·34920	0·30477	W
1775	Yale *16* 8372, 8377, 8390	0·31340	0·38473	0·30187	S
1776	Yale *11* 8216, 8222, 8229	0·42253	0·23924	0·33823	R
1777	Cord. D. 14866, 14904, 14914	0·20238	0·39026	0·40736	R
1778	Yale *16* 529, 537, 554	0·26121	0·49742	0·24137	R
1779	Yale *16* 452, 458, 465	0·39761	0·17695	0·42544	R
1780	Cape *17* 6898, 6912, 6936	0·34978	0·31164	0·33858	R
1781	Cape *17* 6752, 6761, 6782	0·32484	0·40621	0·26895	W
1782	Yale *12* I 7880, 7906, 7908	0·23122	0·45638	0·31240	S
1783	Yale *12* I 7866, 7871, 7886	0·38151	0·25652	0·36197	W
1784	Yale *12* II 8870, 8903, *13* I 8878	0·22379	0·46389	0·31232	S
1785	Yale *17* 4920, 4931, 4936	0·29007	0·45922	0·25071	W
1786	Yale *11* 5300, 5317, 5321	0·24475	0·20061	0·55464	S
1787	Cord. D. 14166, 14167, 14254	0·23073	0·44364	0·32563	R
1788	Cord. D. 13748, 13799, 13844	0·37909	0·22792	0·39299	W
1789	Cape *18* 11233, 11235, 11269	0·24511	0·11624	0·63864	S
1790	Cape *18* 11068, 11094, 11108	0·21689	0·34404	0·43907	R
1791	Yale *13* I 9333, 9340, 9360	0·27787	0·32431	0·39782	R
1792	Yale *11* 8208, 8222, 8230	0·22954	0·40248	0·36798	R
1793	Yale *11* 7770, 7771, 7794	0·38778	0·31620	0·29602	S
1794	Yale *12* I 8150, *11* 7703, 7714	0·37813	0·44374	0·17813	R
1795	Yale *14* 14320, 14355, *13* I 8850	0·39669	0·21388	0·38942	W
1796	Yale *14* 14025, 14028, 14065	0·25614	0·36629	0·37757	S
1797	Yale *13* I 8943, 8970, *14* 14479	0·32954	0·16492	0·50554	W
1798	Yale *13* I 8698, 8707, 8731	0·42402	0·21858	0·35740	S
1799	Cape *18* 8725, 8745, 8765	0·51298	0·18066	0·30635	R
1800	Cord. D. 11845, 11846, 11941	0·41926	0·43671	0·14403	S
1801	Yale *11* 50, 59, *12* I 89	0·20548	0·32229	0·47223	S
1802	Yale *16* 5915, 5921, 5939	0·28351	0·40404	0·31245	R
1803	Cape *18* 10252, 10317, *17* 10825	0·36742	0·37231	0·26027	S
1804	Cape *18* 10242, 10252, 10267	0·53988	0·31235	0·14777	W
1805	Yale *14* 9629, 9645, 9652	0·34576	0·47182	0·18242	W
1806	Yale *12* II 5442, 5445, 5463	0·21960	0·36594	0·41446	W
1807	Yale *12* I 8120, 8123, 8134	0·08275	0·58983	0·32741	S
1808	Cord. D. 14720, 14728, 14746	0·23820	0·28073	0·48107	W
1809	Cord. D. 14534, 14549, 14565	0·40039	0·29193	0·30768	W
1810	Cord. D. 14464, 14466, 14498	0·31563	0·38491	0·29946	R
1811	Cord. D. 14432, 14441, 14457	0·18863	0·44796	0·36341	S

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Some Units and Standards of Weights and Measures

J. W. Humphries*

Presidential Address, 1965

During the course of this address it is proposed to discuss the origin, development and present status of some units and standards of weights and measures. Generally attention will be directed towards those units and standards which have been the concern of the English peoples, but because the Metric System is firmly established in science and technology, and is now assuming an ever-increasing importance in trade, some time must be devoted to a description of this System as well.

Units and Standards of Measurement

It is important to distinguish between units and standards of measurement.

A *unit* of measurement is an abstract conception and cannot be used as the practical basis of a measurement until it has been defined and realized in one of two ways ; either by reference to arbitrary material standards or by reference to natural phenomena, including physical or atomic constants, physical ' situations ' and the properties of specified substances.

In general, a unit is fixed by definition and is independent of such physical conditions as temperature. Examples are the yard, the pound, the gallon, the metre, the gramme.

A *standard* is a physical embodiment of a unit. In general it is not independent of physical conditions, and it is a true embodiment of the unit only under specified conditions, e.g. a yard standard has a length of one yard when at some definite temperature and supported in a certain manner. If supported in a different manner it might have to be at a different temperature in order to have a length of one yard.

Early History

The history of weights and measures goes back into antiquity—how far back we do not know, but according to some authorities there is tenuous evidence to show that weights and measures were in use in Sumeria and Egypt as early as 7000 B.C.

As man emerged from the pre-civilized state of self-sufficiency as a hunter for food and clothing, he began to specialize in elemental crafts such as the making of tools and weapons, growing crops, weaving, making pottery, and the working of metals.

Over a very long period of time and from these primitive beginnings arose the necessity for means to measure. Many are of the opinion that the units first used by primitive man were those of length, followed by the appreciation of two-dimensional area and three-dimensional bulk.

The early established standards of length were derived from limb measurements and are familiar in their developed form in the ancient Egyptian system of measures.

The more abstract idea of mass or weight undoubtedly took longer to dawn on the intelligence of early man. The earliest units of weight included weights of kernels of grain and the weight of shells. Before the crudest weighing instrument was devised the process of hefting or lifting an object to assess its weight was probably in use.

Weighing with the balance ranks amongst the few really fundamental inventions of pre-historic times and is equally important to our civilization as the wheel and axle, the lever and the screw.

Our present knowledge of weights and measures comes from many sources. Some early standards have been recovered by archeologists and are now preserved in museums. The comparison of the dimensions of buildings with the descriptions of contemporary writers is another source of information, e.g. a fairly accurate idea of the length of the Attic foot used by the Greeks has been obtained by comparing the dimensions of the Parthenon with the description given by Plutarch. By studying evidence from all available sources we are able to gain some idea of the origin

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and development of the units. We find that the changes have been gradual because of the large number of modifying influences.

Origin and Development of some Common Units

One of the earliest units was the *foot.* At first this was the length of the unspecified human foot, later it was the length of the foot of the tribal chief or head of state. Not unnaturally its length has varied. In ancient times it was somewhat more than 12 inches but by the time the Greeks arrived it was $11\frac{1}{2}$ inches. The foot was brought to Britain by the Romans and was finally defined in Britain as one-third of the yard during the reign of Edward I. The date is believed to be about 1305.

An important unit of length used by many ancient peoples was the *cubit,* originally defined as the distance from elbow to the tip of the middle finger. About 4000 B.C. the Egyptian cubit was established at a length equal to 18·24 modern English inches. Some authorities claim that it was deduced from measurements of the quarter meridian of the earth. This unit was common to Babylonia, Egypt and later to Assyria. It probably originated in Chaldea. The Egyptian foot was created as a more convenient unit and was made equal to two-thirds of a cubit, or 12·16 inches. Other cubits were later established arbitrarily. Notable among these was the *Egyptian Royal cubit* of 20·64 inches. Egyptian standards passed to Greece and became known as the Olympic standards.

The *inch* was originally a thumb's breadth. In the Roman duodecimal system it was defined as one-twelfth of a foot and as such was introduced into Britain during the occupation.

The *mile* was defined by the Romans as 1000 paces, the pace being equal to 5 Roman feet. This Roman mile when introduced into Britain became 5000 English feet and in Tudor times was changed to 5280 feet.

The *yard* is of much later origin than the units previously mentioned and appears to have a double origin. In Northern Europe it was the length of the girdle worn by the Anglo-Saxons, whilst in southern countries it was the double cubit. There is an old tradition that Henry I decreed that the yard should be the distance from the tip of his nose to the end of his tumb.

One of the earliest of the units of mass or weight was the *grain,* and it is interesting to note that it is a unit which has remained common to several systems of weights and measures throughout the ages. Its origin was probably the weight of a grain of wheat or barley.

The early Egyptian units of weight are of considerable interest since they were the forerunners to some extent of the modern Metric System in that the units of length and mass were inter-related.

The *talent* was the weight of an Egyptian royal cubic foot of water and was divided into 3000 *shekels.* Its weight was 93·65 pounds, making the shekel 218·5 grains, exactly half the ounce of Plantagenet times.

The *Roman pound* (libra) contained 12 ounces (unciae, meaning twelfth parts) of 437 grains each, i.e. the Roman ounce was equal to two Egyptian shekels. This pound was introduced into Britain where it suffered many changes. Eventually during the reign of Elizabeth I, in 1587, two pounds were legalized, viz. the troy pound and the avoirdupois pound. The Elizabethan avoirdupois pound was larger than the Roman pound and contained 16 ounces each of 437·5 grains, the same as the present standard. The idea of a pound divided into sixteen parts was not a new one as the Greeks had divided their pound into sixteen parts as well as into twelve parts.

The history of the pound weight is a fascinating one and is worthy of tracing in more detail.

In later Saxon times the Marc of Cologne was introduced, probably to serve as a standard for the minting of coinage as the 12-ounce Roman pound was already established for trade. With the Norman Conquest, in 1066, the Saxon pound became the Tower or London pound containing 12 ounces each of 450 grains. From the Tower pound were coined 240 silver pennies each of $22\frac{1}{2}$ grains giving 5400 grains to the pound. Apparently this pound became inconveniently small for trading purposes and we find that an additional 'merchants'' pound of 15 tower ounces was in use towards the end of the 13th century. (The exact date of its introduction is uncertain: it may have been in 1266 during the reign of Henry III but 1303, in the reign of Edward I, is considered the more likely.) In addition to the merchants' pound the 'avoirdupois' pound, intended originally for the weighing of wool, came into use and was legalized by Edward III in 1340. This pound contained 16 ounces each of 437 grains, making a pound of 6992 grains; this pound corresponded exactly with one used in Florence.

The 'troy' system had become established in France (the name is derived from the French

town of Troyes) and this too came into use in England. The value adopted after 1414 was a troy pound of 5760 grains containing 12 troy ounces, each of 480 grains. At about the same time the pound used by the German merchants of the Hanseatic League was also coming into use in England. It was the largest one yet and contained 16 tower ounces making 7200 grains. Henry VII, in 1497, authorized yet another 'merchants'' pound of 16 troy ounces, equal to 7680 grains.

The only other change was that made by Queen Elizabeth in 1587, when the value of the avoirdupois pound was adjusted to its present value of 7000 grains.

The various weights which have been in commercial use in England may be summarized thus :

Period	Name of Pound	Equivalent	No. of Grains in Pound
Until 1527 ..	.. Tower or London	12 tower oz. (450 gr.)	5400
Until 1527 ..	.. Merchants'	15 tower oz.	6750
1340–1587 ..	.. Avoirdupois	16 avoirdupois oz. (437 gr.)	6992
Mainly after 1414	.. Troy	12 troy oz. (480 gr.)	5760
Mainly after 1527	.. Hanseatic Merchants'	16 tower oz. or 15 troy oz.	7200
1497 onwards	.. Henry VII Merchants'	16 troy oz.	7680
1587 onwards	.. Queen Elizabeth avoirdupois	16 avoirdupois oz. (437·5 gr.)	7000

The Elizabethan standards of mass and length were to remain the legal English standards for 237 years (1587–1824).

During the intervening years several attempts were made to establish the troy pound as the pre-eminent standard but this did not materialize until 1824. The troy pound which then became the legal standard (the term Imperial Standard was used for the first time) was one which had been made in 1758. This standard weight, along with the other Imperial Standards were irreparably damaged in the fire which destroyed the Houses of Parliament in 1834.

New standards were prepared and finally legalized in 1855, but instead of the Troy pound of 5760 grains, the Avoirdupois pound of 7000 grains was constituted the 'Imperial' measure of weight. The Troy pound, although no longer the primary standard, continued a weight of the realm until the passing of the Weights and Measures Act in 1878, when it was abolished, and the decimal multiples and sub-multiples of the Troy ounce substituted.

At this juncture it will be convenient to leave the Imperial System temporarily and introduce the Metric System.

The Metric System

The Metric System is the international decimal system of weights and measures based on the metre and the kilogramme. Although its origin is generally associated with the French Revolution it really stems from proposals dating back to 1670 and earlier.

For many centuries the kings of France and their ministers had striven in vain against the use of a bewildering variety of weights and measures. They failed for two reasons. One was the general and ingrained opposition to change, the other, the resistance of the seigneurs or petty rulers in the provinces who foresaw that the proposals would prevent them from using two standards with increased profit to themselves. Units varied from province to province and even from town to town ; they varied greatly even within the same province, e.g. in Maine–Loire there were 110 different measures for corn alone ; in the Nord there were 21 varieties of the pound weight. In eighteenth century France, with the largest population in Europe and engaged mainly in agricultural and domestic industry, the situation could only be described as chaotic.

The first effective step towards the formulation and establishment of a national system of weights and measures in decimal notation was taken in France within a year of the Revolution in 1789. The essential features of the system were embodied in a report made to the National Assembly by the Paris Academy of Sciences in 1791. The system became legal in 1795, but its adoption was very slow, and it was not until 1837 that a decree was passed making the use of other than the decimal metric measures a penal offence.

Towards the middle of last century, during a period of increasing industrialization and expansion of foreign trade, it was recognized that some sort of international agreement was necessary in the field of physical measurement. In 1864 the metric system was legalized in

England for use in contracts, but not in trade; in 1867 a convention of the International Geodetic Association recommended the international use of the metric system in geodetic work, and advocated the construction of a new European prototype metre to be available for international use, under the supervision of an international bureau; in 1872 an International Commission, convened by the French Government, met at Paris and supported the recommendations of the Geodetic Association. Finally the Treaty of the Metre was signed in 1875 by representatives of 17 countries (there are now 38 member nations). This treaty provided international agreement on the bases for the metric system, and established the International Bureau of Weights and Measures (the B.I.P.M.) at Sèvres near Paris.

It is interesting to recall that England was not one of the signatories: the Warden of the Standards was a delegate to the 1872 Commission, but was not allowed to participate in subsequent events because 'Her Majesty's Government declared that they could not recommend to Parliament any expenditure connected with the metric system, which is not legalized in this country, nor in support of a permanent institution established in a foreign country for its encouragement. They have consequently declined to take part in the Convention or to contribute to the expenses of the new Metric Bureau, and have directed the Warden of the Standards to decline being appointed a member of the new International Committee or to take part in the direction of the new International Metric Bureau'. Great Britain joined the Metric Convention in 1884.

Units and Standards of the Metric System

At this stage it will be useful to remember that although the metric system is a decimal system, the words 'metric' and 'decimal' are not synonymous and care should be taken not to confuse the two terms.

In the metric system the fundamental units are the metre and the kilogramme. The other units of length and mass, as well as units of area, volume and units such as pressure are derived from these two fundamental units.

The Metre. Originally it was intended that the metre should be one ten-millionth of the meridian quadrant, but during the course of the definitive measurements (made between Dunkirk and Barcelona) it was found that although the general shape of the Earth was that of an oblate spheroid, there were differences in the length of the meridians. Consequently a compromise had to be made so that ultimately the fundamental unit of length became arbitrary and the doctrinaire egalitarianism that had once inspired the revolutionary reformers to measure the meridian common to all men and base upon it a universal system of weights and measures had to be quietly forgotten.

The material standard resulting from these initial endeavours is the Mètre des Archives. It is a platinum bar, 25 mm by 4 mm in section and constitutes an end standard (i.e. the definitive length is the distance between the end faces of the bar).

The present international metric standard of length is the International Prototype Metre. This bar, one of several made for the International Bureau of Weights and Measures between 1872 and 1880, was selected after precise measurements indicated that it was of the same length as the Metre of the Archives. It is an alloy of platinum-iridium (90% Pt, 10% Ir) and is of a special X-form section designed by Tresca to give maximum rigidity in relation to its weight. Two transverse lines are cut on the neutral plane of the bar towards its ends. The Metre was defined as the distance between these lines when the bar is at a temperature of 0°C and supported in a special manner.

The Kilogramme. It was also the intention of the originators of the Metric System that the units of length and mass be inter-related and that this end be achieved by taking the unit of mass to be equal to the mass of one cubic decimetre of distilled water at its maximum density. A series of precise measurements, designed to establish this unit, were commenced in 1791 by Lavoisier and were almost completed two years later when he was arrested. (He was executed in 1794 as a former Farmer-General.) Ultimately the work was completed by Lefevre-Gineau and Fabbroni. The outcome was the Kilogramme des Archives, a platinum standard in the form of a polished cylinder having a diameter of 39 mm equal to its height.

The present standard of mass in the Metric System is the International Prototype Kilogramme. It is of the same platinum-iridium as the International Prototype Metre and retains the form of the Kilogramme des Archives. No reference is made in its definition to the mass of a cubic decimetre of water although it purports to reproduce the mass of the Kilogramme des Archives as closely as possible.

Volume of the Kilogramme of Water. Some doubt was eventually raised as to whether the mass of the Kilogramme des Archives was equal to that of a cubic decimetre of water at 4°C. Between 1895 and 1907 the International Bureau of Weights and Measures undertook to determine the volume of a kilogramme of water and finally concluded that it was $1 \cdot 000\ 028$ cubic decimetres at 4°C under normal atmospheric pressure.

The name ' litre ' was assigned to this volume occupied by the mass of one kilogramme of water.

The Imperial Standards after 1878

The Weights and Measures Act, 1878, adopted as the imperial unit of weight, the weight in vacuo of a certain Pt-Ir cylinder marked PS 1844 1 lb. The imperial standard of length was vested in a bronze bar of square section, its definitive length being the distance, at 62°F, between the middle lines engraved upon gold plugs inserted near the ends of the bar, the latter being supported in a specified manner.

Four copies of each of these standards were prepared at the same time (additional copies have been prepared since), the intention being that they were to be used for the replacement of the primary standard should it ever be lost or damaged. One copy of each standard was immured in the Palace of Westminster and have rarely been disturbed. The Act of 1878 required that the copies of the standards be intercompared every ten years and compared with the Imperial Standards every twenty years, the immured copies being expressly exempt from these requirements.

The Weights and Measures Act, 1878 was superseded in 1963.

In 1897 the use of metric weights and measures was legalized for purposes of trade in Great Britain, the basis of reference being the British national copies of the International Prototypes which had been established in 1889.

Legally therefore, in Great Britain there were two independent systems of weights and measures after 1897, one based on the yard and the pound, the other on the metre and the kilogramme. In these days of increasingly precise measurements such a situation was illogical to say the least.

Of these two systems the family of metric standards were more modern and much more extensive than that of the imperial standards and furthermore they were made from much more durable material. Their stability was known to be excellent, whereas that of the imperial standards, in particular the yard, was open to considerable doubt. In fact by 1947 it had been clearly established that the Imperial Standard Yard had decreased in length by nearly two parts in one million.

This situation lent considerable support to influential groups in science and technology who wished to unify certain of the British and American standards of measurement. (The American standard yard had been linked with the metre since 1893.) Consequently, in 1959, it was decided by the national standards laboratories of the English-speaking world to adopt the definitions,

1 yard $= 0 \cdot 9144$ metre and 1 pound (avoir) $= 0 \cdot 453\ 592\ 37$ kilogramme for use in science and technology.

The Weight and Measures Act, 1963 legalized these relationships in Great Britain so that now the primary standards (the name Imperial Standard has been retained) are related precisely to the standards of the metric system.

Weights and Measures in Australia

Since early colonial days the responsibility for providing standards of weights and measures has been a State matter. The standards held by the States are traceable to the Imperial Standards. It is interesting to recall that the first standards arrived in Australia during 1855 and were distributed to New South Wales, Victoria and Tasmania. They were copies of the Imperial Standards legalized in the same year.

In 1948 we saw indications of changes to come, when the Federal Parliament passed the Weights and Measures (National Standards) Act. This Act was not implemented. It was repealed and replaced by the Weights and Measures (National Standards) Act 1960. To date this Act has not been implemented either, but it is understood that the technical and other difficulties responsible for the delay have been overcome so that we may expect renewed progress in the not-too-distant-future.

The 1960 Act (as did that of 1948) makes provision for the Federal Government to assume responsibility for the establishment of standards of physical measurement for Australia. Whilst this action might appear to be a usurption of State rights by the Commonwealth, you are reminded that provision for such was included in the Constitution.

This Act will legalize, for purposes of trade in Australia, the decisions of 1959 relating to the yard and the pound. It goes much further,

of course, and deals with all manner of physical measurements which are beyond the scope of this address.

There is at least one interesting difference between these recent weights and measures acts of Australia and Great Britain : this relates to the definition of the gallon.

The Weights and Measures Act, 1878, defined the gallon as 'the volume occupied by ten imperial pounds weight of distilled water weighed in air against brass weights, with the water and the air at the temperature of 62 degrees of Fahrenheit's thermometer, and with the barometer at 30 inches'. From a scientific point of view this definition was most unsatisfactory as it lacked precision in that neither the density of the weights nor that of the air or water were stated. Certain densities were adopted by the Board of Trade for these substances and ultimately it was accepted that 1 gallon = 4·545 96 litres.

This latter definition of the gallon has been used in the Commonwealth Act but not in the recent British Act. The latter follows the Act of 1878 but a measure of precision has been injected into the definition by ascribing values to the density of the water, air and weights. Used in conjunction with the pound equal to 0·453 592 37 kilogramme this definition leads to the gallon/litre relationship referred to in the Commonwealth Act.

Present Status of the Metric Standards

Although the International Prototype Standards (and their copies) have proven to be extremely stable, achievements in science and technology have been so vast that it is not surprising to learn that efforts have been made to improve upon them.

The year 1892 saw the first determination of the metre in terms of the wavelength of light. This was carried out at the International Bureau of Weights and Measures by Michelson and Benoit using lines from the spectrum of cadmium.

During the last two decades the controlled use of atomic energy has resulted, among other things, in the production of pure isotopes of many elements. From the metrologist's point of view isotopes of the elements mercury, krypton and cadmium are of particular interest for these are used in the production of light sources suitable for use in interferometry.

After several years of endeavour undertaken by the foremost national standards laboratories in the world, the decision was taken in 1960 at the Eleventh General Conference of Weights and Measures, 'that the metre be defined as equal to 1 650 763·73 times the wavelength in vacuo of the orange-red radiation corresponding to the transition between the energy levels $2p_{10}$ and $5d_5$ of the krypton –86 atom'.

Thus, in one direction at least, the aspirations of the originators of the metric system have been realized : we now have the standard of length vested in a 'natural' standard.

From time to time consideration has been given also to the possibility of relating the standard of mass to some 'natural' standard but little progress has been made. In order to achieve this objective it would be necessary to produce suitable isotopes or compounds of known composition and purity. Purities of the order of one part in 10^{10} would be required for all substances and if a gas were chosen it would require about 10^{26} atoms for each kilogramme. Since our best counting techniques are capable of counting only 10^7 atoms per second we would require 10^{19} seconds to count a kilogramme, and this is longer than the estimated life of the universe!

It seems then that we are saddled with the Pt-Ir kilogramme for the time being at least. But is this as bad as it seems? What could cause significant changes in the International Prototype Kilogramme? Any damage to it which would remove say one in 10^9 of its mass, by way of a scratch, would be readily seen by the naked eye. Oxidation of platinum at normal temperatures is so slow that it has never been measured and no sign of an oxide coating on the metal has ever been noticed. One calculable change is known which will take place. One of the isotopes of platinum, Pt 190, is radioactive and undergoes α-decay with a half-life of 10^{12} years. Since the abundance of this isotope is only 0·012 70 it will take about 10^8 years for it to produce a change equal to the uncertainties in the best measurements. Furthermore, present-day kilogrammes are of fused metal and so are fiee from included gases and hence the changes which might otherwise arise due to the escape of such gases.

All in all then, there appears to be no good practical reason for replacing the International Prototype Kilogramme with a physical constant.

The address was illustrated by a selection of slides.

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The Mathematical Sciences in the Changing World

W. B. Smith-White*

Abstract—Modern living in advanced civilized countries is dependent on a vast application of the results of scientific study of the natural world. The material necessities, comforts and luxuries of our age derive especially from and are by-products of the study of physics, chemistry and geology, the so-called exact sciences. New developments and new applications mount at a fast growing rate. To keep abreast of this progress and to maintain and to service existing and expanding facilities civilized states need a greater and greater proportion of their population trained in numerous special techniques of the most varied kinds. This is possible only on the basis of a general scientific education more widely spread and of greater depth than was ever necessary before. So it is that an ever increasing number of people require a scientific education at secondary and tertiary levels. State expenditure in this cause must be seen in a proper perspective. Enormous increases in expenditure cannot be avoided ; no State can afford to be parsimonious with the scientific education of its citizens.

But States, like individuals, must operate within their means. The money spent must be well spent so as to gain the maximum benefits. Education must be efficient. Students must acquire and retain more or less permanently the principles expounded and the skills taught.

All reforms in systems of education are no doubt directed towards gaining greater benefits more efficiently in time and more economically in cost. How can we approximate the best possible results in the domain of the natural sciences ?

I have indicated already by the title of this address that I think our world is changing. Indeed man himself is changing. This is as true as the theory of evolution. But the rate of change in this case must be quite slow compared with other rates of change which we recognize. For instance, I believe it would be true to say that man, his qualities, instincts, abilities, intelligence, emotions are much the same today as they were 2000 years ago. It is quite different, however, when we regard the external conditions of life, the capacity of man to satisfy his material needs. This capacity—to provide food, clothing, housing, to control disease, to cure sickness, to prolong life—has been magnified in modern times in a proportion which transcends the possible dreams of our ancestors. Man has, in a very large degree, taken control of the world and its forces ; and some people feel that he is ready to extend this control to the stars. He has prospered and multiplied, he has in fact overrun the earth, a phenomenon which is sometimes ominously described as the population explosion.

This mastery of nature has resulted entirely from the study of the ways of nature—what is called the scientific study of nature. Through many ages of pre-history man learned from nature slowly and painfully, by hard and bitter experience. But this was the beginning of science, even though the acquisition and accumulation of knowledge was accidental and unconscious. It was possible only by reason of his human intelligence. The conscious, directed and calculated study of nature which we now understand by science is of very recent origin. It derives from the enquiring mind or natural curiosity of man. But long before this stage was reached, throughout the greater part of recorded history, man's intellectual and cultural activities were concerned with philosophy, religion, metaphysics, logic and pure mathematics. Nature was a mystery and progress towards a rational understanding of the world was hampered by superstition, fear, credulity, and mysticism.

It is in the last 300 years that science has established itself not merely as an absorbing and fascinating study for a fortunate minority of intellectuals with the opportunity and leisure to indulge their fancy, but as an essential ingredient in the structure of a modern civilization. Though not directly engaged in scientific work, technical or otherwise, the majority of people make their livelihood in industries which did not exist 150 years ago, while all of us make daily use of the products of such industries. Trained scientists are required on every hand in much greater numbers than ever before and it appears likely that a point has now been reached when active steps need to be taken at once to ensure that the supply in the immediate future will be able to meet this demand. The only source of supply is the youth population of the country and much depends on the incentives provided for

* Presidential address, delivered on 3rd April, 1963.

a scientific education and the type of scientific education offered in our schools and universities. These questions are very much discussed at the present time, and it is felt generally by people who consider them, that some quite radical changes in our programmes for science must be made. I think so too, but I also think that we must be careful to retain what is good in the traditional courses and be quite certain that the new programmes will work better than the old. In fact, it is my belief that our courses, secondary and tertiary, as they have developed up till now, in science and in mathematics as well, include much more of what is right than of what is wrong. Naturally they should be the subject of continuous revision, but the greatest defects are not in the courses of study themselves, but in the manner of their implementation.

The layman can recognize the importance of science, the diversity of its applications, the complexity of its ramifications, but he can form no idea of what science really is. He is impressed by the latest and most spectacular developments, the astonishing achievements of atomic power, of space satellites and the like. He does not distinguish technological and engineering advances from advances in science. Modern scientific educators seem very prone to make another mistake. Their aim appears to be to drag the beginning student straight up to the frontiers of knowledge and there dazzle him with what the man of science is doing here and now. In their anxiety to reach this goal, they seem to be careless of the risk they run of failure to expound the principles of knowledge and to teach the manner of its use. Any attempt to propound grand unifying concepts for the study of science to hasten along the progress of a beginner, must end in futility. For him as yet there is nothing to unify.

In fact, of course, the fundamental principles of science are not so numerous, not so unrelated, not so incoherent that they cannot be encompassed by any good intelligence. It is rare indeed that any new fundamental principle is discovered. There is no call to race for the frontiers of knowledge lest they, like the horizon, recede as we approach. The object of scientific study is not an encyclopaedic knowledge of facts and figures but a mastery over scientific principles, old and new, and of their application, and to achieve in part some mastery should be the aim of a well-designed scientific education at whatever level.

Because I believe that the chronological development of science has such important lessons for the present-day teaching of science, I hope you will be patient with me when I take a little time to trace the progress in the modern era.

Francis Bacon (1561–1626) elaborated the scientific method. Whereas the Greeks sought explanation of the whole world of phenomena in all its complexity, Bacon stressed the importance of studying the simplest situations. He classified as an impediment to sound knowledge " the impatience of men who want short cuts to a complete explanation of the universe ". What appears subsidiary or of lesser importance may be ignored in the first instance or reserved for later study. Physical situations, he thought, should be simplified and idealized to the point where relations and connections could be perceived. By this means he felt that it might be possible to derive simple, fundamental and general laws of nature.

Galileo (1564–1643) derived such laws for mechanics from the experimental study of motion down an inclined plane, from the motion of a projectile, and from that of a pendulum. Newton worked up this beginning into the science of mechanics almost in the form we know it today. Subsequently it has been shown that this Newtonian mechanics, by mathematical calculations alone, will account for, in minutest detail, all the intricate motions of bodies, solid and fluid, elastic and plastic; all the various motions of the planets, their orbits, precession, nutation, conjunctions, eclipses, tides, etc. Here indeed we have the most notable success of all in the whole of mathematical science. Rockets, artificial satellites, their mechanisms, adjustment and control, depend essentially on mechanics. All this from three simple laws of motion.

As mechanics was the first and perhaps the most complete success for the scientific method, it was also a fundamental preliminary for advance in other branches of science. In mechanics was found first the notable conception of conservation of energy. Here it is necessary to emphasize that conservation of energy in the mechanical context is a theorem derived from Newton's laws and not a new and independent principle. This is sometimes forgotten and in some places has led to gross error which persists even in modern work. The notion of energy historically was introduced into physics via mechanics, and, in my opinion, there is no other rational way of doing so.

Let us pass on to consider heat. One of the first essential steps in the elucidation of this subject was to distinguish between the notions of temperature on the one hand and heat on the other. The first attempts involved the introduction of a subtle imponderable fluid called caloric, which possessed only one property of importance—it was conserved. Caloric could neither be created nor destroyed. The temperature of a body was assumed to be increased or decreased according as caloric flowed into it or flowed from it. Up to a point this caloric theory was quite a good theory—by its means the notions of specific heat, latent heat and the techniques of calorimetry were developed. But this caloric theory had to be abandoned when it was found that the hypothesis of conservation for the caloric fluid was untenable. Rumford's work, just before 1800, showed that the caloric fluid could be continuously created by the continued performance of mechanical work. It was now a short step to the fundamental notion of conservation, but not conservation of mechanical energy, and not conservation of caloric, but conservation of the total (mechanical energy + caloric). This of course implied a quantitative relation between mechanical energy and caloric. But now there is no more need for caloric—it is simply heat, a transform of mechanical energy. This was the first, and epoch-making, extension of the notion of energy from the domain of mechanics to the wider field of physics. It was the origin of this most fertile concept of conservation which was afterwards applied to the whole domain of physical science.

We may note in passing that much the same sequence of ideas occurred again in more recent times. The two independent conservation principles of classical physics, that of mass, and that of energy, have been replaced by conservation of (mass + energy). In fact energy and mass are not now supposed to be separately conserved any more than caloric and mechanical energy are separately conserved. This modern notion comes with the theory of relativity, and in this connection Einstein's relation $E = mc^2$ is the analogue of Joule's relation $W = JH$.

The concept of energy conservation is rightly regarded as a corner stone of physical science and I have tried to remind you how this concept arose by induction from experience—from Newton's mechanics and Rumford's work on the mechanical generation of heat. By contrast to this, how completely unintelligible it must be to a beginner in the study of science, who is totally ignorant of mechanics, to tell him that something called energy is a basic concept of science, that this thing can appear in many forms, and that heat is one such form. Remember that for such a beginner the word energy has no meaning at all. It tells him nothing about heat or about energy to assert that heat is a form of energy, and less than nothing to assert that we live in a moving ocean of energy. This is sheer nonsense, but the words are quoted from a modern science syllabus. It is a denial of the scientific method to postulate the concept of energy at the start and try to derive science from it. It is the converse procedure that is the historical and rational one. In the same way, it is a denial of science to postulate, from the beginning, that matter is composed of elementary particles. Rather the student of science should be shown exactly how the study of natural phenomena leads quite inevitably to the conclusion that matter is built from elementary particles. In the end we can be as certain that these things exist as we can be about any kind of physical existence. But this conviction cannot be induced by the postulational approach.

A few years ago I would have thought it quite un ecessary to dwell at length on these thoughts. Today I am not certain of this. Quite often we hear views expressed that the teaching of science in our schools is obsolete and must be modernized. Some contemporary science critics appear to regard with concern that their children are taught much the same science at school today as they themselves learned perhaps 30 years ago.

Surely, if the scientific principles taught were right then they are still right today. Is it possible or desirable to avoid this? Must we attempt to teach science without discussing and explaining the principles discovered by Newton, Faraday, Joule, Kelvin, Helmholtz, Maxwell, Boltzmann, Planck, Einstein, Rutherford and Bohr? Or do we merely present statements of the principles in an authoritarian manner without giving any clues to the inductive processes which gave birth to them? The science of these men is much more than 30 years old; does it thereby qualify for oblivion? One commentator has written: "One feels that a youngster who has had a science course at school and who has not heard of the developments of the last few decades, who has not in school officially heard something about the escape velocity of a space vehicle, has not really got out of his education what he should". But, in fact, the escape velocity of a space

vehicle, or any other body for that matter, is a trivial consequence of Newton's mechanics. Anyone who has got Newton's mechanics has got this escape velocity and much more as well.

I believe that it is impossible to understand modern science without a good understanding of classical science. Modern science has no very new principles. The scientific method, induction from experience, the setting up of specially devised experiments, the study of simplified and idealized situations, interpretation in the light of hypotheses are part of modern, as of classical, science. Modern theoretical physics derives from classical physics. I do not believe that anyone should begin the study, say, of Wave Mechanics who is in complete ignorance of Newton's mechanics. Mind, I am not saying that it would be logically impossible to do so, but merely that it would be an irrational thing to do.

Science is essentially experimental and quantitative. On the other hand all our observations in nature are initially qualitative. Having observed some effect, we want to be able to reproduce it, we want to note what factors in the physical conditions determine it, which ones were accidental and irrelevant, how we can magnify the effect and what are its implications. For this we must devise means of measuring the effect and of its causal factors. But quantitative estimates involve numerical relationships and quantitative study involves mathematical processes. Here we meet a very real difficulty for the formulation of a programme for instruction in science, one which is recognized by teachers of science, but for which a completely satisfactory solution does not appear to be in sight. The difficulty is simply that the mathematical equipment of beginners is not equal to the proper discussion of the simplest and most fundamental of quantitative studies. I have said that I think mechanics is historically and properly the foundation from which modern science has sprung. But the elucidation of mechanics had to await the appearance on earth of perhaps the greatest mathematical genius of all time—Sir Isaac Newton. How then shall we begin the serious study of science at school? Can we afford to ignore the serious quantitative side of science and concentrate merely on qualitative aspects, reducing our courses to the level of popular science? I do not wish to decry popular science; it serves a very useful and important purpose in presenting an overall picture of the achievements and value of science. It arouses interest, excites wonder and educates. So many people, fascinated by well written popular science, find text-book science and school science courses tedious and dull. Teachers of science are painfully aware of this. How often do they find that the initial enthusiasm of their classes for science has completely evaporated in a year or two!

Text-books and courses in physics nearly always begin with a section on mechanics and the properties of matter. There seems little doubt that these topics are dull unless one is equipped with the mathematics necessary to deal with the problems of interest. What is required is some elementary knowledge of calculus. Newton's second law involves acceleration, but the very definition of acceleration involves the notion of the calculus.

What I think we need is a very close coordination between mathematics courses and science courses so as to teach as early as possible the kind of mathematics most required for quantitative science and to teach the kind of science which is treated most satisfactorily by means of elementary mathematics. In mechanics, my aim would be to derive the mechanical theorem of energy conservation from Newton's laws in the simplest context, viz., that of the uniformly accelerated rectilinear motion of a massive particle. Having once established this energy theorem for the simple case, we would have a basis for its extension into the wider domain of science.

I think also that beginners in science are far more interested in principles and relations than they are in mundane applications. In mathematics, for example, children may be interested in numbers, prime and composite, in properties of divisibility, in highest common factor, and even in puzzle problems whereas commercial problems generally, as profit and loss, stocks and shares, income tax, invoices, etc., they will find unutterably dull. In chemistry similarly, fundamental analyses and syntheses, compositions and relations, will have much more interest than processes which have merely industrial and commercial importance.

The sciences of chemistry, geology, biology, do not seem to be faced with the same kind of initial difficulty as appears for physics, or so it seems to me, possibly because of my almost total ignorance of these subjects. But I think the necessity for the statement of quantitative relationships arise less early in these subjects and are at first of a simpler kind. A much wider preparatory and qualitative study seems to be a necessary preliminary in these subjects. The observed phenomena are so varied that

much more time and thought must be spent in the classification and organization of the field of study before we get to the point where mathematics may be usefully applied. It may even be expedient to begin science studies with these subjects and let the study of physics come later at a time when the student is better prepared mathematically.

As all teachers of science are aware, any theoretical study of science must be accompanied by practical experimental work related to the topics considered. These provide the foundations for the theory as well as fundamental training for the student. Science is much more than mere theory and the trained scientist is a practical man or woman, able to devise new experiments, to interpret the results of experiments and to apply science to practical ends. In fact, it is just these practical people that our community needs in greater and greater numbers, and should be the main or bulk products of secondary school science courses. Most of these will not become advanced students of theoretical science, but they will have the background and training to specialize in one of the numerous fields of applied science, technical, technological and industrial.

The equipment of training laboratories is a costly affair, and much care and thought is required in the selection and construction of apparatus for the experiments which are to be performed. They must be devised with two ends in view—firstly they must provide the factual foundations of the theory and secondly they must provide an opportunity for the acquisition of experimental skill. This second requirement is probably the most important. The student of science must learn about, appreciate and understand the significance of many hundreds of experiments which he never will have the opportunity himself to perform. A good clear description of an experiment and its results must mean as much to the scientist as though he had done it himself. There are many experiments which, because of their difficulty, complexity, cost or other reason, are suitable only as demonstrations by a teacher. Properly discussed, such demonstration experiments have the same theoretical value for the student as though performed by himself.

To summarize what has been said already, I consider that the world of everyday life is changing because of the rapid expansion of scientific applications. Science itself is expanding, but the truth already found and consolidated remains in the same state. Old science continues to find new applications. Scientific method has scarcely changed at all in hundreds of years. To a very great extent the teaching of science should follow along the lines of its historical development, avoiding of course the hundreds of wrong tracks and dead ends which had to be explored. Science training should begin with a survey of the facts and observations which are most significant for the development of theory. The main object is to relate and connect observed phenomena, to study cause and effect. The generalizations to be found will be quantitative relations, not mere qualitative ones. The majority of secondary school students in science will not become practising scientists but many will become valuable workers in industries which apply science. For them more lasting benefit is derived from learning to apply the method of science and from absorbing the most fundamental principles of science than from the few scientific facts that they may keep permanently in the memory.

The teaching of mathematics should be closely coordinated with the teaching of science. The student should be just a little ahead in his mathematics of that required for his scientific work. Throughout our courses, both secondary and tertiary, we find now that just the reverse is true. Over and over again we find that the teachers of science want to use mathematics which the teachers of mathematics have not yet treated. This reacts detrimentally on both mathematics and science. Modern science should be introduced whenever possible, avoiding however some of the mistakes which are very easy to make. Authoritarian descriptions of the conclusions to which modern science has come, however fascinating and exciting, have little value for serious teaching in science. It is a mistake to be carried away by the impressive achievements of modern science and to think that this must be brought down to school level. It is a mistake to echo the parrot cry that our courses are obsolete and that henceforth students must learn first the things last discovered. Certainly there are improvements to be made in existing courses, eliminating things which beginners find dull and tedious, and replacing them by things found stimulating and exciting. Perhaps I may risk one or two illustrations.

The principles of measurement of length, say, by vernier and micrometer are important and simple and easily understood, and they may be explained in a few minutes. If now we ask a student at school to measure the diameter

of a wire 10 times, to take the mean, and to calculate probable error or standard deviation by means of a formula given but not understood, then we will bore him. These are important things in some connections when we want to extract as much accuracy as possible with a given instrument; but they are matters of technique not of principle, and moreover they depend on statistical theory quite beyond the pupil at this stage. He is disgusted by what appears to him, and is for him, a waste of time.

Or again, consider the determination of g by means of a pendulum. I myself find this a fascinating thing to contemplate. This is because I know the theory, which involves the knowledge that the motion of the pendulum is governed by the differential equation $l\ddot{x} + gx = 0$. But when I first met this simple pendulum, I had not heard of differentiation. I was told only to count the number of oscillations and calculate g from the given formula $T = 2\pi\sqrt{\frac{l}{g}}$. The whole business was dull, tedious and disappointing.

To conclude, may I take the liberty to present quite briefly my own personal prescription for the best possible results in science education. They are:

(1) an adequate body of highly trained teachers;
(2) a sound and scientifically designed syllabus;
(3) a well-written text book.

Of these (1) is by far the most important. By trained teachers I mean less trained in the art of teaching than trained in the science they are to teach. The art of teaching is important, but it can be acquired by practice. For most people the science is obtained only by guided study with the help of a master of science. The teacher of science should not finish his study with his qualification for a degree. It is well known that such a qualification may be obtained by scoring 50% in a certain set of examination papers. In the absence of further and continued study, even what has been achieved will soon be lost. I think then that there should be a certain reserve of teachers not engaged in teaching but rather in study; just as an army in action has a reserve in training. The cost of this would not be negligible; but neither would it be prohibitive; perhaps a 10% increase in the salary bill. In any case such a plan should be considered, remembering that it is not the cost only that matters but also what we get for this expenditure.

As regards a syllabus: this should be designed in the first instance by a master in the whole field of the science concerned. The designer should not be selected for specialist knowledge in some small branch or because of specialist research, whatever its value or whatever the recognition it may have achieved. Also he should not be a teacher. As I have said, in general, after many years of teaching and of very little study, most teachers do not have the desirable total mastery of their subject. Of course, a syllabus so prepared would then be examined and modified where necessary in consultation with the most experienced teachers.

For a text book I make no suggestion. Except that I will say that if the first two conditions are achieved, then I think the right text will be quickly produced.

I have spoken long enough. In education in this State, some very important changes are in process at this time, and I believe there are many people with knowledge and experience who are not convinced that some of these constitute progress, but rather the reverse.

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Average Forces in Lossy Electromagnetic Systems

Expressions Involving Measurable Terminal Parameters

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Abstract—For linear electromagnetic systems free of energy losses it is always possible to express average forces in terms of derivatives of effective self and mutual inductances or capacitances at the several input terminal pairs irrespective of the internal details of the system. For lossy systems this is not usually possible. A certain class of lossy systems which includes some important practical cases is described for which the average generalized forces are expressible in terms of measurable terminal parameters alone. In these cases

$$(F_x)_{\mathrm{av}}+(F_x')_{\mathrm{av}}=\mathbf{I}^{(N)\dagger}\partial\overline{\mathbf{L}}/\partial x\mathbf{I}^{(N)}$$

where $\mathbf{I}^{(N)}$ is the r.m.s. terminal-current column-vector, $\overline{\mathbf{L}}$ the effective terminal inductance matrix and $(F_x)_{\mathrm{av}}$, $(F_x')_{\mathrm{av}}$ are average generalized forces for conjugate excitations.

The class of systems corresponds to a variety of practical situations, including the production of electromagnetic levitation forces from eddy currents and the description of perturbations to the ideal behaviour of moving-iron or dynamometer measuring instruments.

(1) Introduction

The estimation of electromagnetically produced forces is important in a wide variety of both theoretical and practical contexts. The forces to be discussed here are average forces arising in alternating current systems from electric or magnetic stresses produced without the need for the application of a static electric or magnetic field. At low frequencies these forces are derived from the electric or magnetic action between charges or current-carrying circuits. At high frequencies, where wave effects are important, they are usually referred to as radiation-pressure forces. The discussion will be confined to low frequencies where retardation effects are unimportant. The deflection forces produced by electrostatic voltmeters, dynamometer and moving-iron instruments and the repulsion forces of electromagnetic levitation are all examples of this type.

It has been shown[(1) (2)] that for linear loss-free systems, the average generalized force $(F_x)_{\mathrm{av}}$ corresponding to a generalized coordinate x may be written entirely in terms of the behaviour of the system *as measured at the input terminals, irrespective of internal construction details.*

$$(F_x)_{\mathrm{av}}=(1/2j\omega)\sum_{K,L} I_K^*(\partial\overline{Z}_{KL}/\partial x)I_L \quad \ldots\ldots (1)$$

$$=(1/2j\omega)\sum_{K,L} V_K^*(\partial\overline{Y}_{KL}/\partial x)V_L \quad \ldots\ldots (2)$$

$$(j=\sqrt{-1})$$

where V_K, I_K are root-mean-square (r.m.s.) complex terminal voltages and currents, and $\overline{Z}_{KL}$, $\overline{Y}_{KL}$ are elements of the terminal impedance and admittance matrices relating to the time dependence $\exp(j\omega t)$.

Equations (1) and (2) are generalizations corresponding to well-known results in electrostatics and magnetostatics, the simplest of which are

$$F_x=\tfrac{1}{2}v^2\partial C/\partial x \quad \ldots\ldots (3)$$

$$F_x=\tfrac{1}{2}i^2\partial L/\partial x \quad \ldots\ldots (4)$$

for the force F_x from a capacitor C charged to a voltage v, or an inductor L carrying a current i. White and Woodson[(3)] obtain related results when non-linear, but nevertheless energy-conserving, processes are encountered.

Unfortunately, all practical systems are necessarily lossy. For some systems the departure from loss-free behaviour may be a minor effect,[1] while for others such as the electromagnetic levitation of metals as discussed in Section (4.1) it may be essential to their operation. The results of equations (1) and (2) are no longer exactly applicable and it does not seem possible in general to express average forces in terms of terminal parameters alone. The difficulties arise essentially from the inapplicability of energy conservation principles when losses occur.

Some recent work on the estimation of electromagnetic levitation forces in axially symmetric systems[4] has shown the levitation force to be expressible in terminal form as

$$(F_x)_{av} = \tfrac{1}{2} I^* I \partial L/\partial x \quad \ldots\ldots (5)$$

$$= (1/2\omega) I^* I \partial X/\partial x \quad \ldots\ldots (6)$$

where I is the r.m.s. current exciting the levitation coil, L, X are its effective inductance and reactance at the angular frequency of excitation ω, and x is the separation of the coil and levitated body. Equations (5) and (6) are in fact the same as some forms of the loss-free results, although the presence of high losses is almost automatic in electromagnetic levitation. This has led to the study of a class of lossy systems for which terminal parameter formulae are derivable.

The model studied is a network consisting of n unchanging but otherwise arbitrary lossy internal meshes coupled reactively to N terminal meshes. Both the reactive coupling between these two sets of meshes, and the terminal mesh impedances themselves (both the resistances and the reactances) may vary arbitrarily with the generalized coordinate x to give contributions to the force $(F_x)_{av}$. Exact terminal parameter expressions are obtained for systems which this model represents.

Practical applications of the results include the estimation of levitation forces from impedance measurements, the absolute calibration of a.c. measuring instruments and the determination of d.c./a.c. transfer characteristics and the frequency sensitivity of measuring instruments.

(2) Circuit Equations of the Network Model

Consider a linear passive reciprocal network excited by N terminal currents $I_A, I_B, \ldots I_K$. These may be conveniently written collectively as an excitation-current or terminal-current column-vector

$$\mathbf{I}^{(N)} = \begin{bmatrix} I_A \\ I_B \\ \cdot \\ \cdot \\ \cdot \\ I_K \end{bmatrix} \quad \ldots\ldots (7)$$

where the index $^{(N)}$ indicates that the column-vector has dimension N. (Bold-face letters are used to indicate matrix quantities.) In addition it is supposed that there are n internal meshes in which further mesh currents $I_1, I_2, \ldots I_n$ flow. This set of internal mesh currents may be written as an internal-mesh-current column-vector,

$$\mathbf{I}^{(N)} = \begin{bmatrix} I_1 \\ I_2 \\ \cdot \\ \cdot \\ \cdot \\ I_n \end{bmatrix} \quad \ldots\ldots (8)$$

It is supposed that the meshes are chosen such that $I_A, I_B, \ldots I_K$; $I_1, I_2, \ldots I_n$ constitute a complete set of independent mesh currents. The complete mesh-current column-vector is then

$$\mathbf{I}^{(N+n)} = \begin{bmatrix} I_A \\ I_B \\ \cdot \\ \cdot \\ \cdot \\ I_K \\ I_1 \\ I_2 \\ \cdot \\ \cdot \\ \cdot \\ I_n \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

The system is assumed to have voltage sources $V_A, V_B, \ldots V_K$ in the N terminal meshes $A, B, \ldots K$ which collectively form the terminal-voltage column vector

$$\mathbf{V}^{(N)} = \begin{bmatrix} V_A \\ V_B \\ \cdot \\ \cdot \\ \cdot \\ V_K \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

Since there are no sources in the internal meshes the complete mesh-voltage column-vector is

$$\mathbf{V}^{(N+n)} = \begin{bmatrix} V_A \\ V_B \\ \cdot \\ \cdot \\ \cdot \\ V_K \\ O \\ \cdot \\ \cdot \\ \cdot \\ O \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

The mesh equations of the network may be written

$$\mathbf{V}^{(N+n)} = \mathbf{Z}^{(N+n)}\mathbf{I}^{(N+n)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

where the $(N+n)$ by $(N+n)$ matrix $\mathbf{Z}^{(N+n)}$ is the impedance matrix of the entire network.

It is useful to write $\mathbf{Z}^{(N+n)}$ in partitioned form to separate the internal and terminal meshes.

$$\mathbf{Z}^{(N+n)} = \left[\begin{array}{c|c} \mathbf{Z}^{(N)} & j\mathbf{X} \\ \hline j\mathbf{X}^T & \mathbf{Z}^{(n)} \end{array}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

where $\mathbf{Z}^{(N)}$ is an N by N matrix, $\mathbf{Z}^{(n)}$ is an n by n matrix, $\mathbf{X}$ is a coupling matrix having N rows and n columns and $\mathbf{X}^T$ denotes the transpose of $\mathbf{X}$. $\mathbf{Z}^{(N+n)}$ may be written in the form of equation (13) since it is symmetric for reciprocal networks. $\mathbf{Z}^{(N)}$ and $\mathbf{Z}^{(n)}$ are also symmetric. In the form of equation (13) $\mathbf{Z}^{(N)}$ and $\mathbf{Z}^{(n)}$ are specific to either the terminal or internal meshes alone and $\mathbf{X}$ contains the interaction between them. The mesh equations (12) in partitioned form become

$$\begin{bmatrix} \mathbf{V}^{(N)} \\ \hline \mathbf{O} \end{bmatrix} = \left[\begin{array}{c|c} \mathbf{Z}^{(N)} & j\mathbf{X} \\ \hline j\mathbf{X}^T & \mathbf{Z}^{(n)} \end{array}\right] \begin{bmatrix} \mathbf{I}^{(N)} \\ \hline \mathbf{I}^{(n)} \end{bmatrix} \quad \ldots\ldots (14)$$

or

$$\mathbf{V}^{(N)} = \mathbf{Z}^{(N)}\mathbf{I}^{(N)} + j\mathbf{X}\mathbf{I}^{(n)} \quad \ldots\ldots (15)$$

$$\mathbf{O} = j\mathbf{X}^T\mathbf{I}^{(N)} + \mathbf{Z}^{(n)}\mathbf{I}^{(n)} \quad \ldots\ldots (16)$$

where $\mathbf{O}$ is a null column-vector.

Equation (16) gives

$$\mathbf{I}^{(n)} = -j(\mathbf{Z}^{(n)})^{-1}\mathbf{X}^T\mathbf{I}^{(N)} \quad \ldots\ldots (17)$$

which expresses the internal mesh currents in terms of the terminal currents. Substitution in equation (15) yields

$$\mathbf{V}^{(N)} = \{\mathbf{Z}^{(N)} + \mathbf{X}(\mathbf{Z}^{(n)})^{-1}\mathbf{X}^T\}\mathbf{I}^{(N)} \quad \ldots\ldots (18)$$

which directly relates the terminal voltages and currents. Thus

$$\overline{\mathbf{Z}} = \mathbf{Z}^{(N)} + \mathbf{X}(\mathbf{Z}^{(n)})^{-1}\mathbf{X}^T \quad \ldots\ldots (19)$$

is the terminal impedance matrix of the network. Notice that $\mathbf{Z}^{(N)}$ alone is not the terminal impedance matrix as the internal meshes have an influence through the coupling by the matrix $\mathbf{X}$.

As yet no specialization has been made regarding the network structure or the dependence of its elements upon the generalized coordinate x. For proceeding further the following restrictions are imposed on the nature of the internal meshes 1, 2, . . . n.

(*a*) The internal mesh parameters are not changed by changes in x, i.e.

$$\partial\mathbf{Z}^{(n)}/\partial x = \mathbf{O} \quad \ldots\ldots (20)$$

($\mathbf{O}$ is the appropriate null matrix).

(*b*) The coupling between the terminal and internal meshes is entirely reactive, i.e. $\mathbf{X}$ is a real matrix and

$$\mathbf{X}^* = \mathbf{X} \quad \ldots\ldots (21)$$

It should be noted that there is no limit at all placed on n the number of internal meshes nor on the form of $\mathbf{Z}^{(n)}$. There is also no restriction on $\mathbf{Z}^{(N)}$ or its x dependence.

Conditions (*a*) and (*b*) are appropriate, for example, in the situation where the internal meshes 1, 2, . . . n are eddy-current meshes and $\mathbf{X}$ represents inductive coupling to them from the terminal meshes. It is this situation which will be of direct interest, although it could happen that conditions (*a*) and (*b*) are satisfied in some other way.

(3) The x-Dependence of the Terminal Parameters and the Force $(F_x)_{\mathrm{av}}$

Equation (18) is now differentiated with respect to x in such a way as to hold the terminal currents $\mathbf{I}^{(N)}$ constant,

$$\begin{aligned}(\partial/\partial x)_{\mathbf{I}}\mathbf{V}^{(N)} = {} & (\partial\mathbf{Z}^{(N)}/\partial x)\mathbf{I}^{(N)} \\ & + (\partial\mathbf{X}/\partial x)(\mathbf{Z}^{(n)})^{-1}\mathbf{X}^T\mathbf{I}^{(N)} \\ & + \mathbf{X}(\mathbf{Z}^{(n)})^{-1}(\partial\mathbf{X}^T/\partial x)\mathbf{I}^{(N)} \quad \ldots\ldots (22)\end{aligned}$$

where use has been made of equation (20) in omitting a term involving $\partial(\mathbf{Z}^{(n)})^{-1}/\partial x$. It is not possible to keep all of the mesh currents unchanged during the differentiation. In general only the terminal currents I_A, I_B, . . . I_K may be held constant and $(\partial/\partial x)_{\mathbf{I}}$ has this meaning.

Equation (22) is a column-vector equation involving N separate equations. From it a single scalar equation may be obtained by forming

$$\mathbf{I}^{(N)\dagger}(\partial/\partial x)_{\mathbf{I}}\mathbf{V}^{(N)}$$

where † denotes the Hermitian conjugate matrix. The Hermitian conjugate matrix is the transposed complex-conjugate matrix, for example

$$\mathbf{I}^{(N)\dagger}=[I_A^*,\ I_B^*,\ .\ .\ .\ I_K^*] \qquad (23)$$

This gives

$$\begin{aligned}\mathbf{I}^{(N)\dagger}(\partial/\partial x)_{\mathbf{I}}\mathbf{V}^{(N)}=&\mathbf{I}^{(N)\dagger}(\partial\mathbf{Z}^{(N)}/\partial x)\mathbf{I}^{(N)}\\&+\mathbf{I}^{(N)\dagger}(\partial\mathbf{X}/\partial x)(\mathbf{Z}^{(n)})^{-1}\mathbf{X}^T\mathbf{I}^{(N)}\\&+\mathbf{I}^{(N)\dagger}\mathbf{X}(\mathbf{Z}^{(n)})^{-1}(\partial\mathbf{X}^T/\partial x)\mathbf{I}^{(N)} \qquad (24)\end{aligned}$$

$$\begin{aligned}&=\mathbf{I}^{(N)\dagger}(\partial\mathbf{Z}^{(N)}/\partial x)\mathbf{I}^{(N)}+j\mathbf{I}^{(N)\dagger}(\partial\mathbf{X}/\partial x)\mathbf{I}^{(n)}\\&\quad+\mathbf{I}^{(N)\dagger}\mathbf{X}(\mathbf{Z}^{(n)})^{-1}(\partial\mathbf{X}^T/\partial x)\mathbf{I}^{(N)}\\&\quad\text{by use of equation (17)} \qquad (25)\end{aligned}$$

$$\begin{aligned}&=\mathbf{I}^{(N)\dagger}(\partial\mathbf{Z}^{(N)}/\partial x)\mathbf{I}^{(N)}+j\mathbf{I}^{(N)\dagger}(\partial\mathbf{X}/\partial x)\mathbf{I}^{(n)}\\&\quad+\mathbf{I}^{(N)T}(\partial\mathbf{X}/\partial x)(\mathbf{Z}^{(n)})^{-1}\mathbf{X}^T\mathbf{I}^{(N)*} \qquad (26)\end{aligned}$$

by taking the transpose of the last term in equation (25) and using the symmetry of $\mathbf{Z}^{(n)}$.

The following notation is now introduced:

$$\mathbf{I}^{(n)'}=-j(\mathbf{Z}^{(n)})^{-1}\mathbf{X}^T\mathbf{I}^{(N)*} \qquad (27)$$

From equation (17), $\mathbf{I}^{(n)'}$ has the physical significance of being the internal-mesh-current column-vector produced by the application of terminal currents $\mathbf{I}^{(N)*}$ rather than $\mathbf{I}^{(N)}$. Equation (26) becomes

$$\begin{aligned}(\partial P/\partial x)_{\mathbf{I}}=&\mathbf{I}^{(N)\dagger}(\partial\mathbf{Z}^{(N)}/\partial x)\mathbf{I}^{(N)}\\&+j\mathbf{I}^{(N)\dagger}(\partial\mathbf{X}/\partial x)\mathbf{I}^{(n)}\\&+j\mathbf{I}^{(N)T}(\partial\mathbf{X}/\partial x)\mathbf{I}^{(n)'} \qquad (28)\end{aligned}$$

$$\text{where } P=\mathbf{I}^{(N)\dagger}\mathbf{V}^{(N)} \qquad (29)$$

$$=\mathbf{I}^{(N)\dagger}\overline{\mathbf{Z}}\mathbf{I}^{(N)} \qquad (30)$$

is the complex power flow to the network.

From the theory of forces developed previously[1] the force $(F_x)_{\text{av}}$ may be written

$$\begin{aligned}(F_x)_{\text{av}}=(1/2\omega)[&\mathscr{I}\{\mathbf{I}^{(N)\dagger}(\partial\mathbf{Z}^{(N)}/\partial x)\mathbf{I}^{(N)}\}\\&+\mathbf{I}^{(N)\dagger}(\partial\mathbf{X}/\partial x)\mathbf{I}^{(n)}\\&+\mathbf{I}^{(N)T}(\partial\mathbf{X}/\partial x)\mathbf{I}^{(n)*}] \qquad (31)\end{aligned}$$

where use has been made of equation (20) and the fact that $\mathbf{X}$ represents reactive coupling between the terminal and internal meshes.

Now suppose that the network excitation produces terminal currents $\mathbf{I}^{(N)*}$ rather than $\mathbf{I}^{(N)}$, and denote the resulting force by $(F')_{\text{av}}$, then

$$\begin{aligned}(F_x')_{\text{av}}=(1/2\omega)[&\mathscr{I}\{\mathbf{I}^{(N)\dagger}(\partial\mathbf{Z}^{(N)}/\partial x)\mathbf{I}^{(N)}\}\\&+\mathbf{I}^{(N)\dagger}(\partial\mathbf{X}/\partial x)\mathbf{I}^{(n)'*}\\&+\mathbf{I}^{(N)T}(\partial\mathbf{X}/\partial x)\mathbf{I}^{(n)'}] \qquad (32)\end{aligned}$$

By addition of equations (31) and (32)

$$\begin{aligned}2\omega\{(F_x)_{\text{av}}+(F_x')_{\text{av}}\}=2\mathscr{I}&\{\mathbf{I}^{(N)\dagger}(\partial\mathbf{Z}^{(N)}/\partial x)\mathbf{I}^{(N)}\}\\&+\mathbf{I}^{(N)\dagger}(\partial\mathbf{X}/\partial x)\mathbf{I}^{(n)}+\mathbf{I}^{(N)T}(\partial\mathbf{X}/\partial x)\mathbf{I}^{(n)*}\\&+\mathbf{I}^{(N)T}(\partial\mathbf{X}/\partial x)\mathbf{I}^{(n)'}+\mathbf{I}^{(N)\dagger}(\partial\mathbf{X}/\partial x)\mathbf{I}^{(n)'*} \qquad (33)\end{aligned}$$

However, from equations (28) and (21) equation (33) becomes

$$2j\omega\{(F_x)_{av}+(F_x')_{av}\}=(\partial P/\partial x)_{\mathrm{I}}-(\partial P/\partial x)_{\mathrm{I}}^* \quad \text{(34)}$$

or

$$\omega\{(F_x)_{av}+(F_x')_{av}\}=\mathscr{I}\{(\partial P/\partial x)_{\mathrm{I}}\} \quad \text{(35)}$$

This is the basic result of the paper. The right-hand side will be expressed in terms of terminal parameters which are directly measurable irrespective of the details of the internal meshes.

The simple form of equation (35) is due in part to the involvement of the combination $\{(F_x)_{av}+(F_x')_{av}\}$ rather than $(F_x)_{av}$ alone. In general $(F_x)_{av}$ and $(F_x')_{av}$, the force obtained by reversing the relative phases of all exciting currents, are slightly different. Referring to equations (31) and (32) it is seen that the first contribution involving $(\partial \mathbf{Z}^{(N)}/\partial x)$ is not changed. However, the terms from the coupling to the internal meshes are not equivalent, and

$$\begin{aligned}2\omega\{(F_x)_{av}-(F_x')_{av}\}&=\mathbf{I}^{(N)\dagger}(\partial \mathbf{X}/\partial x)(\mathbf{I}^{(n)}-\mathbf{I}^{(n)'*})\\&\quad+\mathbf{I}^{(N)T}(\partial \mathbf{X}/\partial x)(\mathbf{I}^{(n)*}-\mathbf{I}^{(n)'}) \quad \text{(36)}\end{aligned}$$

Use of equation (17) in equation (36) gives

$$\begin{aligned}2\omega\{(F_x)_{av}-(F_x')_{av}\}&=j\mathbf{I}^{(N)\dagger}[\mathbf{X}\{(\mathbf{Z}^{(n)})^{-1}+(\mathbf{Z}^{(n)})^{-1*}\}(\partial \mathbf{X}^T/\partial x)\\&\quad-(\partial \mathbf{X}/\partial x)\{(\mathbf{Z}^{(n)})^{-1}+(\mathbf{Z}^{(n)})^{-1*}\}\mathbf{X}^T]\mathbf{I}^{(N)} \quad \text{(37)}\end{aligned}$$

The matrix in the square brackets on the right-hand side of equation (37) is seen to be skew symmetric, so that

$$(F_x)_{av}=(F_x')_{av} \quad \text{(38)}$$

if all elements of $\mathbf{I}^{(N)}$ have the same or opposite phases. Of course equation (38) is also true for the trivial case of no internal mesh coupling, for which

$$\mathbf{X}=\mathbf{O} \quad \text{(39)}$$

Returning to equation (35) it may be observed that this result resembles an earlier result,[1] but the specializations of Section (2) and the particular choice of constants in the differentiation have ensured that there is no term involving the internal meshes explicitly.

Use of equation (30) in equation (35) gives the terminal-impedance form

$$\begin{aligned}\omega\{(F_x)_{av}+(F_x')_{av}\}&=\mathscr{I}\{\mathbf{I}^{(N)\dagger}(\partial \overline{\mathbf{Z}}/\partial x)\mathbf{I}^{(N)}\} \quad \text{(40)}\\&=\mathbf{I}^{(N)\dagger}(\partial \overline{\mathbf{X}}/\partial x)\mathbf{I}^{(N)} \quad \text{(41)}\end{aligned}$$

where $\overline{\mathbf{X}}=\mathscr{I}(\overline{\mathbf{Z}})$ (42)

is the terminal reactance matrix. For a single terminal-pair network equation (41) becomes simply

$$(F_x)_{av}=(1/2\omega)I^*I(\partial X/\partial x) \quad \text{(43)}$$

where X is the reactance of the network and I the current flowing.

The analysis has considered a single frequency of excitation. Should the system be simultaneously excited at a number of frequencies the average forces from the individual components are additive,[1] [2] and each may be evaluated separately.

(4) Applications

(4.1) Electromagnetic Levitation

In recent years there has been interest in the levitation and melting of alloys and metals by the production of high-frequency eddy currents.[5] [6] The reaction of the eddy currents on the excitation coil produces the force used for levitation. The levitation force may be estimated crudely from the approximate theory of Okress and his collaborators,[5] or more accurately from a detailed field solution if this is practicable.[7] The field solution of Brisley and Thornton for a sphere on the axis of an axially symmetric coil-system[7] was used by Smith[4] to show that in this case the levitation force may be written

$$(F_x)_{av}=\tfrac{1}{2}I^*I(\partial L/\partial x) \quad \text{(44)}$$

where L is the effective inductance of the coil, I the exciting current, and x the separation of the coil and sphere. Equation (44) leads to a procedure for predicting levitation forces from low-level impedance measurements. Equation (44) was also derived using a circuit-theory model of the eddy-current system, but the axial symmetry was important in obtaining the final result.[4]

However, a system of the type considered in Sections (2) and (3) is appropriate as a model of electromagnetic levitation under more general conditions. Each of the internal meshes 1, 2, . . . n (no restriction on n, which may be increased without limit) represents an eddy-current mesh and their excitation is caused by inductive coupling to the excitation coils. The conditions (*a*) and (*b*) of Section (2) are clearly appropriate and the results of Section (3) give the levitation force $(F_x)_{\mathrm{av}}$ if x is the vertical coordinate of the levitated body. The term in $(\partial\mathbf{Z}^{(N)}/\partial x)$ in equation (31) would be zero unless the levitated body were magnetic. In the usual levitation experiment a single coil is used and equation (43) gives the levitation force. Introduction of the effective inductance,

$$L=X/\omega \qquad (45)$$

gives equation (44) as an alternative form.

Thus levitation forces may be deduced indirectly from low-level measurements of inductance changes. At the same time a measurement of the effective series resistance R introduced by the presence of the levitated material gives the heating I^*IR to be expected. The amount of heat generated is very important in practice[6] and is controlled by a careful choice of frequency. Conversely, existing levitation measurements and calculations may be used to predict the effect of the presence of conducting bodies on the effective inductance of nearby coil systems.

Electromagnetic levitation systems do not usually employ multiple coil systems excited by currents of arbitrary relative phases, but equation (41) is valid should they do so.

(4.2) Moving-Iron Measuring Instruments

A moving-iron measuring instrument may be represented by the same model as used for electromagnetic levitation in Section (4.1). Of course the object on which the force is exerted would normally be magnetic. For a two-terminal instrument equations (43) and (44) apply. For a multi-terminal instrument equation (41) must be used. Of course the derivation does not allow for non-linearity effects associated with hysteresis if ferromagnetic material is present.

(4.3) Dynamometer Measuring Instruments

Dynamometer type instruments are important in the laboratory for the measurement of voltages, currents or power, and as d.c./a.c. transfer instruments. The ideal operation may be described in terms of impedance, admittance or mutual inductance changes between circuits.[1] [2] Careful design and construction eliminates any effects from electric forces, dielectric loss or ferromagnetic materials, but there always remain perturbations from the generation of eddy currents. The results of Section (3) apply even when eddy currents are present, since the internal meshes account for eddy-current behaviour.

Referring to equation (31), the generalized deflecting force $(F_x)_{\mathrm{av}}$ is produced almost entirely by the first term involving $(\partial\mathbf{Z}^{(N)}/\partial x)$. This term gives the ideal behaviour of the instrument, the remaining terms being small corrections for eddy-current effects. Likewise, $(F_x)_{\mathrm{av}}$ and $(F_x')_{\mathrm{av}}$ are very nearly equal, since from equations (36) or (37) any difference is due to eddy currents. Equation (41) may be used for finding the deflecting forces

$$\omega\{(F_x)_{\mathrm{av}}+(F_x')_{\mathrm{av}}\}=\mathbf{I}^{(N)\dagger}(\partial\overline{\mathbf{X}}/\partial x)\mathbf{I}^{(N)} \qquad (46)$$

This equation may also be cast into inductance terms by the introduction of an effective terminal-inductance matrix

$$\overline{\mathbf{L}}=\overline{\mathbf{X}}/\omega \qquad (47)$$

giving

$$(F_x)_{\mathrm{av}}+(F_x')_{\mathrm{av}}=\mathbf{I}^{(N)\dagger}(\partial\overline{\mathbf{L}}/\partial x)\mathbf{I}^{(N)} \qquad (48)$$

From the definition of $\overline{\mathbf{L}}$ it is seen that the element L_{AB} is the effective mutual inductance between terminal circuits A and B. Measurements of $\partial\overline{\mathbf{X}}/\partial x$ or $\partial\overline{\mathbf{L}}/\partial x$ at the terminals may then be used for absolute calibration of these instruments.[1]

(5) Conclusions

It has been shown that for a particular class of networks the average generalized force $(F_x)_{\text{av}}$ may be written in terms of the dependence of terminal parameters on the generalized coordinate x. The networks chosen are shown to be appropriate models of the electromagnetic levitation of conductors, and of moving-iron or dynamometer measuring instruments. The results obtained are generalizations of previous work[1] [2] relating to loss-free or almost loss-free systems. When cast in terms of effective inductance the results are almost identical to magnetostatic results such as that given by equation (4). However, the inductances occurring in equation (44) and (48) are effective inductances at the excitation frequency, which allows for the complex internal eddy-current behaviour.

When applied to the electromagnetic levitation problem the results provide an alternative procedure for estimating levitation forces by low-level measurements of reactance. Alternatively, existing calculations of electromagnetic levitation forces provide information on inductance changes produced by the presence of conducting objects. An earlier investigation obtained equations (43) and (44) for the levitation of a sphere by an axially symmetric coil system, but it has now been shown that these equations are of general applicability.

The application of equations (46) and (48) to moving-iron, and more importantly, dynamometer instruments, is of particular interest to measurements laboratories. In principle it allows absolute calibrations to be made in terms of previously established impedance standards. Measurements of the rates of change of reactance or effective inductance with x, together with the deflecting force $(F_x)_{\text{av}}$ provide an absolute measure of the exciting currents. Alternatively, measurements of the effective inductance derivatives at different frequencies give the frequency dependence of a measuring instrument. This is important for dynamometer instruments used as precision d.c./a.c. transfer instruments. It is important that the effects of losses, although small, be included since it is just such minor perturbations which give rise to d.c./a.c. transfer errors. By considering the limit as the excitation frequency ω is reduced to zero, it should be possible to estimate the d.c./a.c. transfer error from impedance measurements as an alternative to direct techniques such as that employed by Smith and Clothier.[8]

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The Marine Permian Formations of the Cracow District, Queensland

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Abstract—In the extreme south-east of the Bowen Basin the basal Permian volcanics (Camboon Andesite) are immediately overlain by calcareous clastics, formerly regarded as one Formation (Oxtrack Formation of Derrington *et al.*, 1959) but considered herein, mainly on faunal grounds, to be divided by a disconformity to give two units :—Buffel Formation (Artinskian-Sakmarian in age) and Oxtrack Formation in a restricted sense (Kungurian-Kazanian) each with its distinct fauna. The greater part of the marine sequence near Cracow belongs to presumed equivalents of the Barfield and Flat Top Formations of the Theodore-Banana District, mainly non-calcareous strata of Lower Kazanian age.

Fossil lists of all spěcies, showing their local stratigraphic ranges, are given.

Introduction

The Cracow District, situated about 250 miles north-west of Brisbane, is in the extreme south-eastern portion of the Bowen Basin. A detailed study of the geology was made during 1961 and 1962 while the writer was at the University of Queensland. In early 1963 work by the writer for Utah Development Company in the Theodore-Banana district to the north of Cracow provided correlation with the Cracow section.

Before 1961 the stratigraphical terms used in the area were those of Derrington *et al.* (1959) who had mapped the area for Mines Administration Pty. Ltd. in 1954. Prior to this, Jensen (1926) and Denmead (1937, 1938) had discussed the marine Permian. Mack (1963) mapped a much larger area from Theodore to Narrabri, N.S.W. The stratigraphical terms used by previous authors are revised in this paper.

A perusal by the writer of the fossil collections in the University of Queensland from Cracow had shown that there were two very different faunas, both being found in the Oxtrack Formation (Derrington *et al.*, 1959). There seemed to be a possibility of an unrecognised disconformity falling within the Formation. Field studies with a view to elucidating the faunal break were carried out. The result of this was that the Oxtrack Formation was shown to contain two distinct lithological and palaeontological units in some places and in other places only one unit was present. In the writer's opinion, Derrington *et al.* have used the term Oxtrack Formation in two senses. In a restricted sense it refers to the section in Oxtrack Creek, the type locality of the Oxtrack Formation but in a wider sense, their description of the distribution ("Narrow outcropping pattern from Cracow Homestead to Banana") refers to two units which the writer has termed Oxtrack Formation (restricted sense) and Buffel Formation. The two Formations are readily distinguished west of Rose's Pride Mine and west of Cracow Homestead.

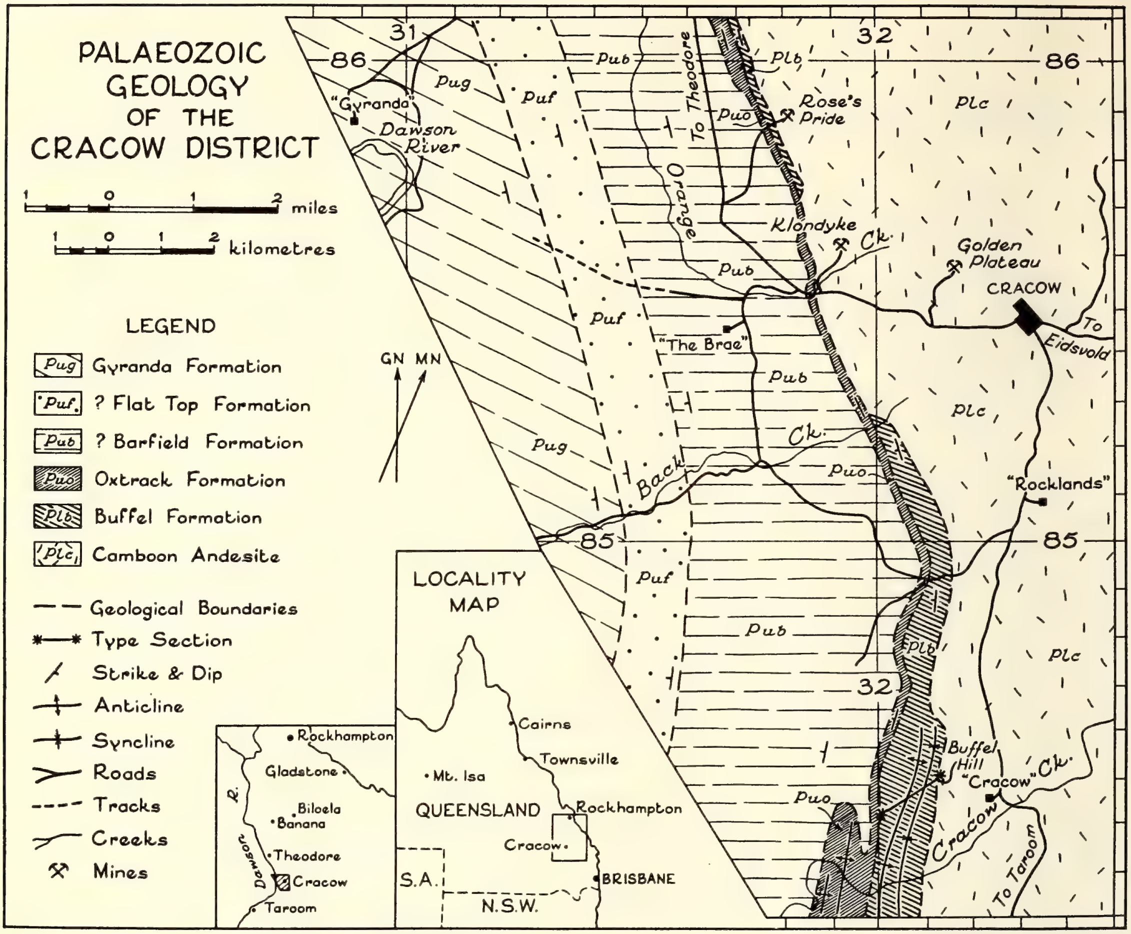
To assist in current geological work in the Bowen Basin this paper is being published as an account of the stratigraphy of the marine Permian and is accompanied by short notes on the palaeontology. Systematic descriptions of new species will appear at a later date. Because of soil cover causing discontinuous outcrop an understanding of the geology of the district is largely dependent on an understanding of the palaeontology; detailed descriptions of the various rock types present are not included.

All map references refer to the Mundubbera 1 : 253,440 military map. There are few geographic place names in the area and exact grid references are given in the text for additional accuracy.

Stratigraphy

The lowest Permian unit in the Cracow district is the Camboon Andesite (Derrington *et al.*, 1959). In this paper the name is used in their sense. One notable addition to the knowledge of this unit is the presence of *Glossopteris* sp. in shales interbedded in the andesite indicating its Permian age. Because of the faunal assemblage in the overlying Formation the Camboon Andesite is regarded as Lower Permian.

A new name, the Buffel Formation, is proposed for the lowest stratigraphical unit overlying the Camboon Andesite.



Buffel Formation

Synonymy: Lower Bowen (in part) Denmead, 1937; Lower Bowen Marine Beds (in part) Denmead, 1938; Oxtrack Formation (in part) Derrington *et al.*, 1959; Back Creek Formation (in part) Mack, 1963. *N.B.*—The terms of Denmead (1937) are taken from the map legend (1937, p. 194) and those of Denmead (1938) from the text.

Derivation: The name is derived from Buffel Hill, 32128447, 3,600 feet at 290 degrees from Cracow Homestead.

Type Section: This outcrops from Buffel Hill, west to 32018441.

Distribution: The Formation, which is found in places as a northerly trending belt throughout the Cracow district crops out in the southern part from south-west of Cracow Homestead to 1·8 miles south-east of the Orange Creek road crossing (32078526). It is not found in the vicinity of the Theodore Road, near the Orange Creek road crossing (31868554). Outcrop is found north of a point, 1·2 miles north of the Orange Creek road crossing (31858573). There, the Formation crops out on the eastern side of small, undulating hills. It does not occur in Oxtrack Creek, the type locality of the Oxtrack Formation. This is 15 miles north of Cracow.

Lithology: Predominantly limestone and siltstones with less amounts of subgreywacke, conglomerate, spiculite, and containing some concretions.

In the type section the Formation consists mainly of fossiliferous limestones which grade upwards to spiculite, which in turn passes into siltstone with calcareous concretions. South of the type section the limestone becomes finer grained and darker but the upper lithologies are not exposed.

To the north of Buffel Hill the limestone outcrops for 1·7 miles (to 32138483) and is replaced along strike by calcareous siltstone. Northwards from a point 3·3 miles north of Buffel Hill (32138507) the siltstone fails to outcrop and along strike a calcareous petromictic orthoconglomerate appears at a point, 1·8 miles south-east of the Orange Creek road crossing (32078526). The conglomerate is composed of andesite fragments set in a carbonate matrix. The fragments are similar to the Camboon Andesite and are considered to have been derived from the older unit. The limestone, calcareous siltstone and conglomerate are all overlain by the spiculite.

The conglomerate is regarded as being part of the Buffel Formation because it occupies the same stratigraphic position as the limestone of the type locality, having the Camboon Andesite directly underlying it. It contains the same fauna as the limestone. Defining the conglomerate as a member of the Formation would be to no advantage.

North of the Theodore Road, the lithology varies from calcareous subgreywacke to limestone. Northwards along strike the lithology becomes more calcareous and coarser grained till a conglomerate, similar to that described before, outcrops 0·8 miles north-north-west of Rose's Pride Mine (31748601). The andesitic fragments here are much larger, being up to six inches in diameter with a mean diameter of 1·5 inches.

Thickness: In the type section, a practically complete exposure is 640 feet thick. This comprises 270 feet of limestone, 350 feet of spiculite and approximately 20 feet of siltstone with calcareous concretions.

The thickness decreases to the north and at Rose's Pride Mine, an approximate thickness of 75 feet is exposed.

Structures: In general, the Buffel Formation dips west at angles between 12 and 35 degrees, but west of Cracow Homestead the Formation is folded into an asymmetrical syncline with a southerly plunge. The western limb dips at 40 degrees to the east. The strike of the Formation varies from 30 degrees west of north to 10 degrees east of north. To the south of the area this variation increases.

Stylolites and chert nodules, together with grain orientation are developed in the limestones of the type section. The stylolites are lensoidal and, in part, are parallel to the bedding. Their lensoidal outline has some relation to the chert nodules for these are of the same shape.

Stratigraphic Relationships: On faunal grounds, the Buffel Formation is considered by the writer to be disconformably overlain by the Oxtrack Formation (as found in Oxtrack Creek). Additional evidence to support this conclusion is gained from isopach maps of the Bowen Basin (Malone, 1964). The exact relationship of the Buffel Formation to the underlying Camboon Andesite is not known, but it may be one of disconformity. This tentative conclusion is reached because of the change from a volcanic to a carbonate facies and because of the andesite pebbles contained by the conglomerates found at the base of the Buffel Formation.

Fauna: Characteristic fossils are *Eurydesma hobartense* (Johnston), *Taeniothaerus subquadratus* (Morris), *Anidanthus springsurensis* (Booker), *Terrakea pollex* Hill, *Strophalosia preovalis* Maxwell, *Ingelarella denmeadi* Campbell, *Platyschisma rotundatum* (Morris) and *Keeneia ocula* (Sowerby).

Age: Lower Permian. This is discussed in the section on palaeontology.

Oxtrack Formation

The Oxtrack Formation is here restricted to the upper lithological and palaeontological unit in the Oxtrack Formation of Derrington *et al.* for which the type locality was Oxtrack Creek, between Cracow and Theodore. Just north of Oxtrack Creek the Buffel Formation is found, but in the creek section itself, only the Oxtrack Formation (in the restricted sense) is to be seen.

Synonymy: This is the same as for the Buffel Formation.

Distribution: The Formation outcrops as a discontinuous northerly trending belt throughout the Cracow-Theodore district. South from the type section the unit can be traced along the western slopes of the small, undulating hills towards the Theodore Road, west of Cracow. From north of Rose's Pride Mine, southwards (to 31848573) the Buffel and Oxtrack Formations outcrop as parallel, adjacent belts, but beyond that point and as far as 1·8 miles south-east of the Orange Creek road crossing (32078526) the Oxtrack Formation directly overlies the Camboon Andesite. South of Back Creek

the Buffel Formation reappears between the Oxtrack Formation and the Camboon Andesite, and the strike swings to east of north. At all localities where the Oxtrack and Buffel Formations are in close proximity, the contact is obscured by soil cover and therefore their angular relationship is not accurately known.

Lithology: The dominant rock types are calcareous siltstones and limestones, both being fossiliferous. The calcareous siltstones occur to the south-west of Cracow and become more calcareous to the north, grading into limestones. The rocks contain a large percentage of organic fragments, mainly polyzoan and crinoidal. This percentage may be as high as 80%, but in the main it varies between 35% and 45%.

The calcareous siltstones of the Oxtrack Formation are more compact than those of the Buffel Formation and the limestones of the Oxtrack Formation are more impure than those of the Buffel Formation.

Thickness: Accurate thicknesses are difficult to obtain because of the soil cover. From Mt. Ox, north of Oxtrack Creek to south of the Theodore Road, the thickness is of the order of 75 to 100 feet. South-west of Cracow Homestead, the thickness is of the order of 300 feet.

Structures: The dip of the Formation varies from 18 to 40 degrees to the west, and the strike varies from 20 degrees west of north to 10 degrees east of north. South-west of Cracow Homestead, the Formation is folded into two asymmetrical anticlines.

Sedimentary structures include orientation of the polyzoan fragments and spines along planes which may be bedding planes. At one locality, 1·3 miles north-west of Cracow Homestead (32018456) there is a grading of both inorganic grains and organic fragments in the siltstone.

Stratigraphic Relationships: The Oxtrack Formation is considered by the writer to disconformably overlie the Buffel Formation and the Camboon Andesite. No evidence has been found for an angular discordance between the Buffel Formation and the Oxtrack Formation. In all places where the two Formations have been observed in close proximity they can be readily distinguished by the faunal assemblages and by the lithological differences, which, although small, are sufficient for discrimination.

Fauna: Characteristic fossils are *Ingelarella mantuanensis* Campbell, *Strophalosia clarkei* Etheridge, Snr., *Strophalosia clarkei* var. *minima* Maxwell, *Martinia* sp., *Atomodesma* (*Aphanaia*) sp., *Volsellina* ? *mytiliformis* Etheridge.

Age: Upper Permian. See section on palaeontology.

Overlying the Oxtrack Formation is approximately 5,300 feet of marine Permian, most of this being fossiliferous. Further to the north in the Theodore-Banana district, Derrington *et al.* named the Barfield and Flat Top Formations in that ascending order. However, because of the extensive tract of soil cover in the Theodore-Cracow district it is doubtful in the writer's opinion whether the Barfield and Flat Top Formations can be definitely related to the sequence at Cracow without the aid of subsurface data. Therefore, the names Barfield and Flat Top are preceded by a question mark in the following text.

? Barfield Formation

This Formation was proposed by Derrington *et al.* for a sequence of rocks conformably overlying the Oxtrack Formation at the type locality, Barfield Station, north-east of Theodore. There the unit comprises mudstone, siltstone and subgreywacke, with calcareous concretions.

Synonymy: Lower Bowen (in part) Denmead, 1937; Middle Bowen (in part) Denmead, 1938; Orange Creek Formation, Acacia Formation, Passion Hill Formation, Derrington *et al.*, 1959; Back Creek Formation (in part) Mack, 1963.

Distribution: In the Cracow district the ? Barfield Formation outcrops only sparsely, forming the black soil plain west of the Oxtrack Formation. The best outcrops were found in creeks cutting this plain such as Orange Creek, Back Creek, and Cracow Creek.

Lithology: Predominantly mudstone and siltstone, with lesser amounts of subgreywacke and tuff. Tuffs are found in the uppermost 500 feet of the sequence as are concretions up to two feet in diameter. The concretions are enclosed in a rock which varies from a subgreywacke to a mudstone. This rock often contains pyrite and glendonites. The glendonites are found with the concretions west of the Newstella yards on "Gyranda," approximately 7·0 miles north of Cracow.

The concretions can also be observed in Back Creek (31668520) and where Orange Creek cuts the road from "Gyranda" to the Theodore Road.

Thickness: Estimated thickness in the Cracow district is 3,250 feet.

Structures: Sedimentary structures are absent except for glendonites and cone-in-cone limestone which outcrops in the black soil plain, 3·1 miles south-west of Cracow (31958505). The significance of glendonites and their origin has been discussed by Carey and Ahmad (1961).

The dip of the Formation varies from 12 to 28 degrees to the west and the strike varies from 20 degrees west of north to 10 degrees east of north.

Stratigraphic Relationships: The ? Barfield Formation in the Cracow district is considered by the writer to conformably overlie the Oxtrack Formation, and to be conformably overlain by the ? Flat Top Formation.

Fauna: This is characterised by *Cancrinella* sp. nov., *Lissochonetes brevisulcus* Waterhouse, *Glyptoleda glomerata* Fletcher, *Paraconularia derwentensis* (Johnston).

Age: Upper Permian. See section on palaeontology.

? Flat Top Formation

The Formation was proposed by Derrington *et al.* for a sequence of rocks conformably overlying the Barfield Formation in the Theodore-Banana district. The type locality was given as four miles east of Banana on the Dawson Highway to Biloela. The lithologies present were mudstones and subgreywackes, with lenses of limestone.

Synonymy: Lower Bowen (in part) Denmead, 1937; Middle Bowen (in part) Denmead, 1938; Mt. Steel Formation (in part) Derrington *et al.* 1959; Back Creek Formation (in part), Kianga Formation (in part) Mack, 1963.

Distribution: The ? Formation outcrops as a series of discontinuous ridges west of the black soil plain in which the ? Barfield Formation outcrops.

Lithology: Predominantly mudstone with minor amounts of calcareous subgreywacke and tuffs showing shards. The mudstones, if light coloured, exhibit a laminated structure and often show small slump structures. Fossiliferous rocks are rare in this ? Formation in the Cracow district.

Thickness: Estimated thickness of the ? Flat Top Formation is 1,900 feet.

Structures: The dip varies from 10 to 25 degrees to the west and the strike varies from 30 degrees west of north to 15 degrees east of north. Minor slumping is evident in some outcrops.

Stratigraphic Relationships: The ? Flat Top Formation is regarded as being conformably overlain by the Gyranda Formation, which contains a *Glossopteris* flora and is considered to be of non-marine origin.

Fauna: The fauna in the Cracow district is composed of crinoid stems. A more complete list of fossils found in the Cracow-Theodore district appears in the section on palaeontology.

Age: Upper Permian. This is discussed in the palaeontology.

Palaeontology

The prolific nature of the faunas in the Cracow district in number of species and genera as well as of individuals has been known since late last century.

There are three main faunal assemblages in the district and to the north around Theodore there are four, as the ? Flat Top Formation becomes more fossiliferous than it is to the south. Some of the fauna from the Buffel and the Oxtrack Formations had been collected previously by Professor Dorothy Hill and other senior staff members of the University of Queensland. The fauna in the ? Barfield Formation had possibly been found before the present work but had not been collected in detail, nor had its lateral extent been established.

The importance of palaeontology in understanding the area can be gauged if a section is taken west from Rose's Pride Mine up through the sequence. Overlying the Camboon Andesite are outcrops of the Buffel, Oxtrack, ? Barfield and ? Flat Top Formations, all fossiliferous, consisting of calcareous clastic sediments and all separated by black soil.

The fossil lists for each Formation are shown in Tables 1 and 2 with the range of each species. A number immediately after a species indicates that some comment is made on that species after the general discussion of the fauna.

Faunal Discussion

Buffel Formation : The Formation contains the lowest marine fauna in the Cracow district. At all localities where the horizon has been recognised it is characterised by the presence of either *Eurydesma* or one of the gastropods, *Keeneia* or *Platyschisma.*

Cancrinella farleyensis may be easily distinguished from species in overlying Formations by its smaller size, finer costation and poorer transverse wrinkling. *Terrakea pollex* is characterised by its small size and absence of umbonal thickening, distinguishing it from species in overlying Formations.

Species of *Spirifer, Trigonotreta* and *Neospirifer* from the Buffel Formation have coarser ribbing with a deeper sulcus and higher fold than the species in the Oxtrack Formation. *Spirifer* sp. B. from the ? Barfield Formation is a very alate form.

The ingelarellids are charactered by plications and the species of *Lissochonetes* is not as globose as *L. brevisulcus* from the ? Barfield Formation.

Hill (1950), after studying the Productinae came to the conclusion that the age of the fauna was Upper Sakmarian or Lower Artinskian. Maxwell (1954), after a study of the species of *Strophalosia* came to a similar conclusion. Hill (1955), on evidence gained from the previous two studies as well as from the ingelarellids, placed the age as uppermost Sakmarian. After a complete study of the fauna it is thought that the age is most conveniently placed at the Artinskian-Sakmarian boundary.

In the type section the limestone may be divided into three parts. In the lowest part the fauna comprises a brachiopod-molluscan assemblage, the only polyzoan present being a large ramose stenoporid. Notably absent from the basal assemblage are *Anidanthus springsurensis, Cancrinella farleyensis* and *Horridonia mitis.* Many of the species found in the lowest part are not found in the middle part which contains Foraminifera. *Euryphyllum reidi* is found only in this part and there is a great increase in the number of slender, ramose polyzoa. Associated with these are many

Species	Buffel Fm.	Oxtrack Fm.	? Barfield Fm.	? Flat Top Fm.
Calcitornella sp.	—	—		
Euryphyllum reidi Hill	—			
Anidanthus springsurensis (Booker)	—			
Cancrinella farleyensis (Etheridge and Dun)	—			
Chonetes cracowensis Etheridge	—			
Horridonia mitis Hill (1)	—			
Grantonia sp. nov. (2)	—			
Ingelarella denmeadi Campbell	—			
I. ovata Campbell	—			
I. cf. *profunda* Campbell (3)	—			
? *Krotovia* sp.	—			
Lissochonetes cf. *yarrolensis* Maxwell	—			
Neospirifer sp. (2)	—	—		
Spirifer sp. A.	—	—		
Spiriferellina sp.	—		—	
Strophalosia preovalis Maxwell	—			
Streptorhynchus sp.	—			
Taeniothaerus subquadratus (Morris)	—			
T. subquadratus var. *cracowensis* Hill	—			
Terrakea pollex Hill	—			
Trigonotreta cf. *stokesi* Koenig (2)	—	—		
Chaenomya sp.	—		—	—
Deltopecten limaeformis (Morris)	—			
Eurydesma hobartense (Johnston)	—			
Myonia carinata (Morris)	—			
Keeneia sp. nov. (4)	—			
K. ocula (Sowerby)	—			
Peruvispira sp. nov. (5)	—			
Platyschisma rotundatum (Morris)	—			
Ptychomphalina sp.	—			
Polyzoa (6)	—	—	—	—
Glossopteris sp.	—		—	

Note : (1), (2), etc., refer to notes on species in text.

Species	Buffel Fm.	Oxtrack Fm.	? Barfield Fm.	? Flat Top Fm.
Ammodiscus multicinctus Crespin and Parr		—		
Frondicularia woodwardi Howchin		—		
Rectoglandulina serocoldensis (Crespin)		—		
Cladochonus sp.		—	—	
Euryphyllum sp. A.		—		
Thamnopora wilkinsoni (Etheridge)		—		
? Cancrinella sp.		—		
Ingelarella mantuanensis Campbell		—		
Martinia sp.		—		
Strophalosia clarkei Etheridge, Snr.		—		
S. clarkei var. *minima* Maxwell		—		
Terrakea solida (Etheridge and Dun)		—		—
Atomodesma (*Aphanaia*) sp. (7)		—		
Streblochondria sp.		—	—	
Volsellina ? mytiliformis (Etheridge)		—		—
Euryphyllum sp. B.			—	
Thamnopora cf. *immensa* Hill			—	
Cancrinella sp. nov. (8)			—	
Cleiothyridina sp.			—	
Ingelarella sp. A.			—	—
Lissochonetes brevisulcus Waterhouse			—	
Spirifer sp. B.			—	
Strophalosia cf. *ovalis* Maxwell			—	—
Terrakea sp. A.			—	
Glyptoleda glomerata Fletcher			—	
Platyteichum sp.			—	
Strotostoma sp.			—	
Warthia sp.			—	
Paraconularia derwentensis (Johnston)			—	
Conularia cf. *laevigata* Morris			—	
Lissochonetes sp. (9)				—
Aviculopecten sp.				—

NOTE : (1), (2), etc., refer to notes on species in text.

specimens of *Horridonia mitis* together with *Streptorhynchus* sp. In the upper part the rock is decalcified and it is here that *Anidanthus springsurensis*, *Cancrinella farleyensis*, *Strophalosia preovalis* and *Terrakea pollex* become prominent.

North of the Theodore Road, the Buffel Formation contains fewer specimens, and in particular Polyzoa, *Ingelarella*, *Cancrinella* and *Euryphyllum* are fewer. At Rose's Pride Mine the Formation outcrops as two horizons separated by soil cover ; in similar lithologies, both contain the same fauna but not necessarily in the same proportions.

Oxtrack Formation : The fauna of this Formation is characterised at practically all localities by *Ingelarella mantuanensis*, *Volsellina ? mytiliformis* and large crinoid ossicles up to one inch in diameter.

The species of *Strophalosia* are not as concavo-convex as the species in the overlying Formations. *Ingelarella mantuanensis* is a broad form with long subparallel adminicula and species found in the overlying ? Barfield and ? Flat Top Formations are more globose with a sharper median sulcus.

Maxwell (1954) correlates the fauna with the Mantuan *Productus* Bed and regards the age as high in the Kungurian. Hill (1955) also regards the age as being high in the Kungurian. The Mantuan *Productus* Bed is the upper part of the Peawaddy Formation of Mollan *et al.*, 1964. In the writer's opinion the fauna of the Oxtrack Formation enables correlation to be made with the lower part of the Peawaddy Formation and the age of the fauna is Kungurian-Kazanian.

? Barfield Formation : At all localities where the fauna of the ? Barfield Formation can be observed it is characterised by a species of *Cancrinella* which appears to be the same as *Cancrinella* cf. *magniplica* Campbell (1953, pl. 1, figs. 6–8). It is considered by the writer to be a new species, easily distinguishable from *C. magniplica*.

At first sight this fauna bears some resemblance to that of the Ingelara Formation at Springsure. However, the resemblance is regarded as being ecological.

Most of the genera which are of use in correlation bear some similarity to those in the Oxtrack Formation and as the ? Barfield Formation overlies the Oxtrack Formation without any apparent discordance, the age of the fauna is considered to be Lower Kazanian.

? Flat Top Formation: The presence of *Strophalosia* cf. *ovalis, Terrakea solida* and *Volsellina ? mytiliformis* indicates that the ? Flat Top Formation is equivalent or higher than the Mantuan *Productus* Bed. From the fauna and the stratigraphic position of the ? Formation, the age is regarded as Lower Kazanian.

Notes on Species

(1) In her paper on the Productinae of the Cracow fauna, Hill (1950) erected *Horridonia mitis* but added that there were no specimens showing enough of the dorsal valve for its description. From the type locality and localities to the north, specimens of both ventral and dorsal valves of a form similar to *H. mitis* have been collected and they are being examined by Dr. D. J. Gobbett of the University of Malaysia for their precise determination. If they are specimens of *Horridonia mitis,* a description of them will appear in another paper.

(2) Brown (1953) in erecting the genus *Grantonia* mentioned that specimens from Mt. Britton (Homevale) showed some variation from the Tasmanian topotype material. Specimens from the Buffel Formation are conspecific with those from Mt. Britton and can be readily distinguished from the type species by their ornament. There is some difference in the internal structures of the ventral and dorsal valve.

Plastotype material of the type species of the genera *Neospirifer, Trigonotreta* and *Grantonia* has been studied and the following conclusions reached.

(*a*) *Neospirifer* has bundles of fine ribs. There may be any number on each side of the sulcus and fold and each bundle may contain four to 10 fine ribs. The ornament may be reflected on the internal mould. If any fasciculation takes place it can be observed close to the umbo.

(*b*) *Trigonotreta* has seven bundles of ribs on each side of the sulcus and fold. The ribs are coarser than in *Neospirifer* and only three make up each bundle. In juvenile specimens, fasciculation is found only on outer ribs, but in mature specimens, it is seen on the ribs adjacent to the sulcus. The external ornament is rarely reflected on an internal mould.

(*c*) *Grantonia* has three or four bundles of ribs on each side of the sulcus. Fasciculation is found on both outer and inner ribs. The external ornament is reflected on the internal mould. The observations about *Neospirifer* and *Trigonotreta* are similar to those of Waterhouse (1964).

(3) The specimens appear to be intermediate between *Ingelarella symmetrica* Campbell and *I. profunda*.

(4) *Keeneia* sp. nov. shows some resemblance to *K. minor* (Fletcher) which has a more flattened whorl profile together with more whorls. All other Australian species of *Keeneia* are much larger and have a greater or lesser pleural angle with a different number of whorls.

(5) *Peruvispira* sp. nov. differs from other species in the pleural angle, length/width ratio, number of whorls and size.

(6) The Polyzoa are being studied at present by the writer at the University of Sydney as part of a Ph.D. project.

(7) Previously, this species had been referred to *Astartila pusilla* (McCoy). Bruce Runnegar, University of Queensland, has informed me that the name used in the fossil lists is more correct.

(8) This species is easily distinguished from *Cancrinella magniplica* by the greater convexity of the ventral valve, the much larger size of the visceral cavity, the coarser costations and by the stronger transverse wrinkling on the anterior portion of the ventral valve.

(9) *Lissochonetes* sp. bears some resemblance to *L. brevisulcus*, but preservation is too poor to enable a precise determination to be made.

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Note Added in Proof

Since this paper has gone to press, a specimen of a terebratuloid sent by the writer to Dr. K. S. W. Campbell has been identified and described by him as *Maorielasma callosum* sp. nov. The specimen comes from the Barfield Formation.—B.M.R. Bull. 68.

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The Geology of the Canowindra East Area, N.S.W.

W. R. Ryall

Abstract—An investigation of the geology of an area to the east of Canowindra, N.S.W. (Stevens, 1951, 1954), has shown that nine formations can be mapped within the area and that they extend in time from Middle Ordovician to Upper Silurian. New palaeontological finds have enabled the age of the Canomodine Limestone to be defined as Upper Ordovician and that of all but the uppermost part of the Millambri Formation as pre-Silurian. The Silurian sediments occurring in the area have been placed in four new formations which make up the Cudal Group. A new interpretation has been placed on the Canowindra Porphyry, it now being considered a flow rather than a sill. The structure of the area has been clarified and is shown to be essentially a syncline flanked by anticlines. Two north-south trending thrust-faults, each indicating considerable vertical movement, are prominent features of the area.

Introduction

The area discussed in this paper is about 60 square miles in area and is located astride the Belubula River some five miles east of Canowindra which is itself about 200 miles by road west of Sydney (Fig. 1).

The area has received geological attention since 1919 when Carne and Jones reported on the limestone deposits on Canomodine station. The area has been examined by N.S.W. Geological Survey who were investigating likely dam sites on the Belubula River (Harper, 1931 ; Kenny, 1941 ; Mulholland, 1946).

The first detailed work in the area was undertaken by N. C. Stevens (1950 ; 1951 ; 1952 ; 1954) who mapped the area at the scale of one inch to a mile as part of a much larger regional study embracing the area from Orange to Cowra. Stevens (1954) described and named several of the formations discussed in this paper and wherever possible these names have been retained. More detailed work has, however, required that some of Stevens' formations be changed. Stevens did not subdivide the Silurian sediments in the area, he called them the Cudal Shale—this term has been given group status and four new formations have been placed in it.

New palaeontological finds have enabled the ages of the Canomodine Limestone and the Millambri Formation to be more closely defined. Because of the relatively few graptolites found within the Silurian formations the ages suggested in this paper may need to be modified slightly as new finds are made.

This paper forms part of a thesis presented at the University of Sydney in 1963, as partial requirement for the degree of Bachelor of Science with honours. Detailed petrographic and palaeontological descriptions together with X-ray powder studies of the garnets can be found in the thesis which is housed in the library of the Department of Geology and Geophysics.

Stratigraphy

The area to the east of Canowindra consists of volcanic and sedimentary rocks which were deposited in the Tasman Geosyncline from Lower or Middle Ordovician times to Upper Silurian times. The rocks of the area have been placed in nine formations which are summarized in Table I.

The Cargo Andesite

The Cargo Andesite comprises a number of intermediate to basic volcanic flows which, with interbedded shale and limestone horizons, outcrops near the village of Cargo. The formation was named and described by Stevens (1948, 1950 and 1954). In the Canowindra—Cargo area the rocks of this formation form the oldest units exposed.

In the area examined only the uppermost part of the formation is present and this outcrops as a wedge-shaped exposure over about four square miles. The stratigraphic position of it cannot be determined since both east and west limits are faulted for their entire length of outcrop. However, north-east of the area, where the formation outcrops again, bedded Canomodine Limestone dips off massive andesite clearly showing that it underlies the Limestone. The junction of the two units is not exposed so that it cannot be said if they are conformable.

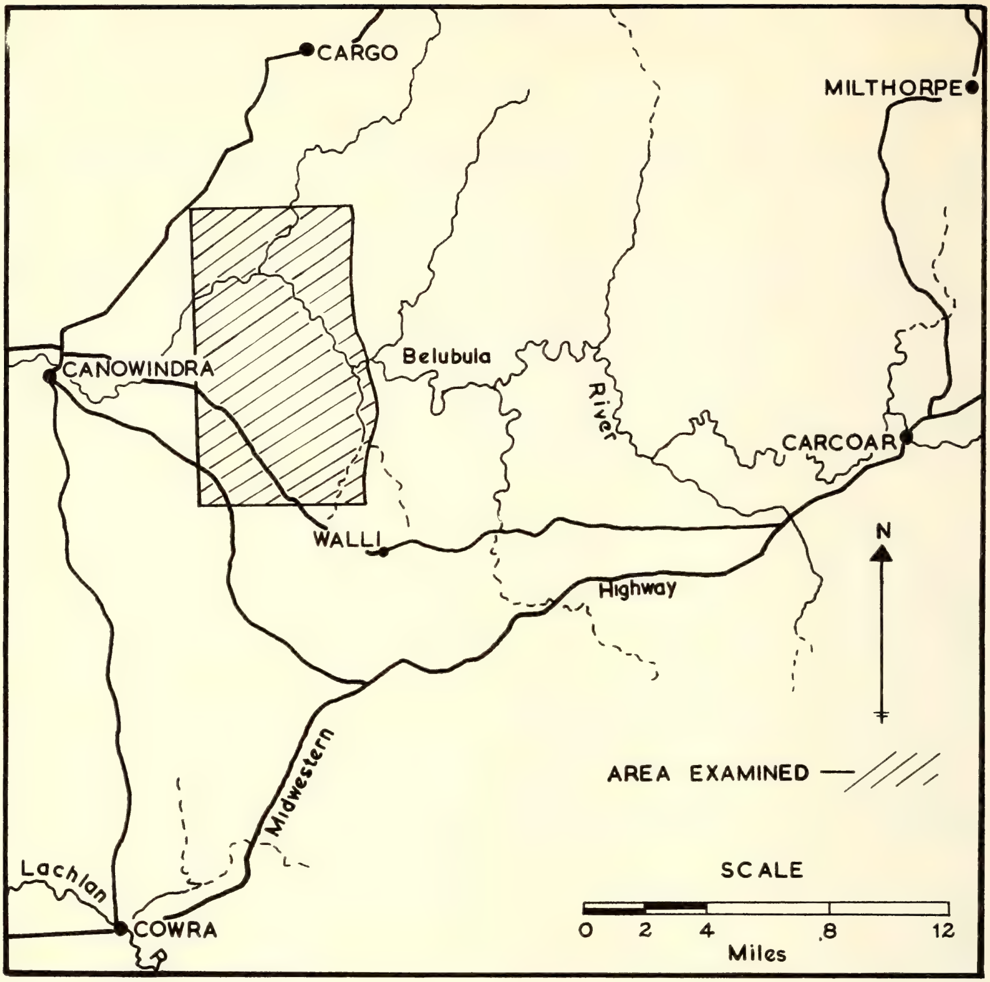


FIG. 1—Locality Map

Near the southern limit of outcrop occurs a large mass of limestone, underlain by about 300 feet of well bedded red, green and brown shales, which was thought by previous workers (Stevens, 1954 ; Adamson and Trueman, 1962) to be part of a Silurian formation (possibly the Wallace Shale of Stevens, 1954) which had been isolated by the complex Columbine Mountain Thrust. It now seems certain that this limestone-shale unit is part of a large lens within the Cargo Andesite since andesitic lavas lie directly over the limestone resulting in its being coarsely recrystallized at the top.

Augite andesites are by far the most common rocks in the formation and predominate over hornblende andesites and basalts. Augite andesites are generally coloured blue in hand-specimen and in thin-section are seen to be composed of phenocrysts of euhedral pyroxene crystals and plagioclase laths set in a fine grained pilotaxitic-subtrachytic groundmass which is composed of plagioclase microlites with interstitial pyroxene, quartz, chlorite, carbonate and potash feldspar. Magnetite granules are irregularly scattered throughout the groundmass.

Plagioclase laths are sometimes up to 5 mm in length and all are more or less completely sericitized and many are albitized. The pyroxene is nearly always augite and occurs as euhedral phenocrysts which are fresh in places but are often partially or wholly replaced by either carbonate or chlorite. Hypersthene occurs rarely as phenocrysts.

Hornblende andesites occur only near the top of the formation and are composed of

TABLE I

	Age	Formation		Thickness
SILURIAN	Upper	Tenandra Formation	CUDAL GROUP	over 1,200 feet
SILURIAN	Upper	Belubula Shale	CUDAL GROUP	700
SILURIAN	Middle	Ghost Hill Formation	CUDAL GROUP	450
SILURIAN	Middle	Upper Avoca Valley Shale	CUDAL GROUP	1,200
SILURIAN	Lower	Canowindra Porphyry	CUDAL GROUP	ca. 1,000
SILURIAN	Lower	Lower Avoca Valley Shale	CUDAL GROUP	340
ORDOVICIAN	Upper	Millambri Formation		4,100
ORDOVICIAN	Upper	Rockdale Formation		250
ORDOVICIAN	Middle	Canomodine Limestone		1,200
		— ? — ? — ? — ? — ? — ? —		
ORDOVICIAN	Lower	Cargo Andesite		over 1,500

large platy phenocrysts of green hornblende with large tabular phenocrysts of plagioclase (near Ab_{36}, though much is albitized) and smaller augite phenocrysts set in a felted or granular groundmass consisting of plagioclase microlites with interstitial potash feldspar, hornblende and quartz.

The andesites contain few amygdules which are infilled with chlorite, calcite or quartz.

All the andesites examined in thin-section show some degree of alteration. Such alteration occurs over the entire area of outcrop, so that it seems unlikely it all can be attributed to deuteric phenomena (Wilshire, 1959). It may well be that some of the alteration effects are due to deuteric action but these cannot be separated from alteration produced by deep-seated diagenesis. Such alteration includes albitization and sericitization of the plagioclase and replacement of pyroxene, amphibole or the groundmass by carbonate or chlorite.

The andesites contain many xenoliths which are sedimentary fragments and andesitic inclusions. The latter are always rounded and have a similar mineralogical composition as the host, though they are invariably of coarser grainsize.

No fauna has been found in any unit of this formation making accurate age-dating impossible. From information obtained from overlying formations, however, it seems that the upper limit of the formation may be about upper Middle Ordovician.

The Canomodine Limestone

The Canomodine Limestone outcrops as a belt one to two miles wide which extends from Canomodine station on the Belubula River,

north about six miles towards the village of Barragan. It forms one of the largest limestone outcrops in New South Wales and about one half of this formation as defined by Stevens (1954) outcrops within the area examined. Within this area the Canomodine Limestone forms the core of the Cranky Rock Anticline and around it the younger formations are folded.

The formation consists entirely of about 1200 feet of light grey, massive, poorly-bedded limestone. Bedding characteristics are obscured by the strongly developed regional cleavage but in places it is defined by rows of siliceons nodules. Rather marked recrystallization has occurred within the limestone and accounts for the poor preservation of the fauna found within it.

Outcropping in the north east of the area is the Cargo Creek Limestone (Stevens, 1954). This mass occurs at a similar stratigraphic horizon as the Canomodine Limestone and appears to be separated from it by fairly simple folding, so that the two masses should properly be regarded as being the one unit.

The Canomodine Limestone is poor in faunal content compared with other limestone masses of similar age which outcrop in the Cudal-Canowindra-Walli area (Stevens, 1954).

Professor Hill has identified from Stevens' collection (Hill, 1957) : ? *Plasmopora* ? *cargoensis* sp. nov., ? *Plasmoporella* ? *inflata* sp. nov., *Propora* sp., *Streptelasma* sp., ? *Lichenaria* sp. and *Stromatoporidae*. From this fauna she suggested that the age of the Canomodine Limestone may be either Upper Ordovician or Lower Silurian.

Further collection has yielded further fauna : *Plasmoporella inflata*, *Calapoecia* aff. *canadensis*, *Favistella inflata*, *Favosites* sp., *Streptelasma* sp., *Tryplasma* sp. and *Stromatoporidae*. This fauna suggests the formation may be pre-Silurian. Evidence obtained from graptolites occurring in the overlying formation indicates that the Canomodine Limestone may be lower Upper Ordovician or even earlier.

Rockdale Formation

The Rockdale Formation is a new formation which has been erected to take the place of the Lower Millambri Formation of Stevens (1950, 1954). Full formation status is warranted since the lithology represented by it differs markedly from that of the Millambri Formation (as now defined). The formation is so named because its maximum outcrop occurs on the " Rockdale " property.

The Formation consists of about 250 feet of soft, finely interbanded dark and light siltstones. Throughout all its outcrop no detritus coarser than siltstone grainsize is present. The silts are composed of angular grains of quartz and feldspar which, in grain-size, grade into a fine grained silty matrix which is often carbonaceous.

The formation contains graptolites but most are poorly preserved. The most diverse fauna occurs at " The Glen " where have been found : *Climacograptus bicornis*, *Dicellograptus* sp., *Climacograptus* sp. and *Glyptograptus* sp.

The identification of *Climacograptus bicornis* and *Dicellograptus* sp. is unquestionable and indicates an upper Ordovician age for the formation. This age conflicts with that assigned by Sherrard (1962) who records the following fauna from " The Glen " : *Monograptus gregarius* (common), *M. atavus*, *M.* cf. *triangulatus triangulatus*, *Glyptograptus tamariscus*, *Climacograptus innotatus* and ? *Dimorphograptus erectus*. From this assemblage she states (pp. 174–175) : " This assemblage from The Glen . . . proves definitely the Silurian age of the Millambri Formation at that locality ".

At The Glen I have not been able to find any Monograptids. The Diplograptids and Leptograptids are unquestionable and require the formation to be assigned to the Upper Ordovician.

Millambri Formation

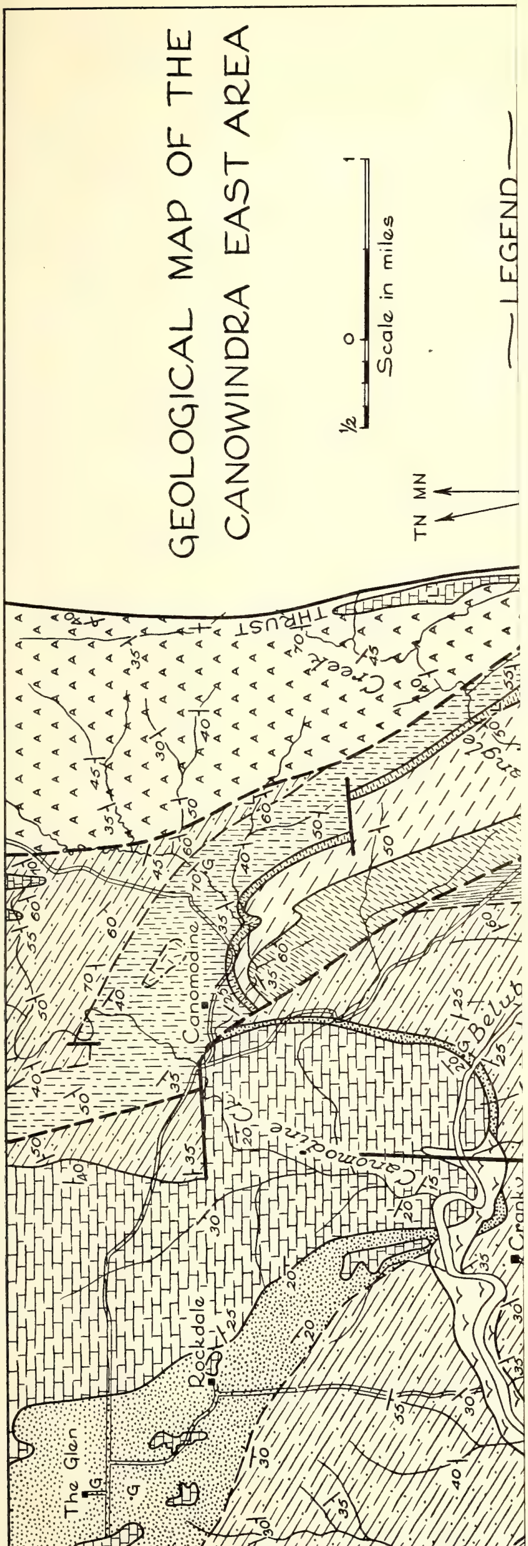
The Millambri Formation is composed of arenites (in the sense of Pettijohn, 1957) and siltstones which conformably overlie the Rockdale Formation around the Cranky Rock Anticline and unconformably overlie the Cargo Creek Limestone at the north eastern corner of the area examined.

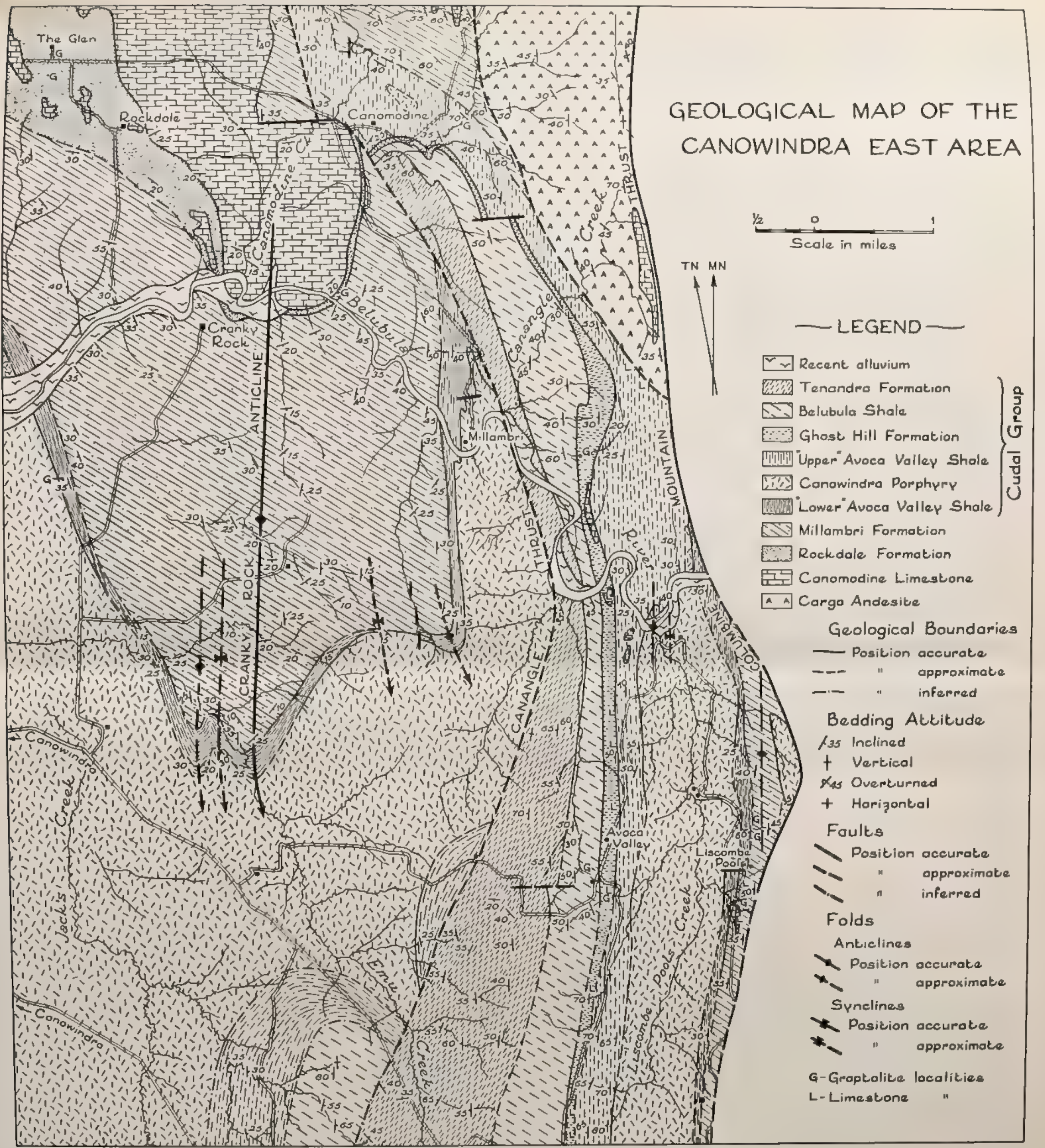
The type section is located at the Belubula River between Millambri and Cranky Rock homesteads where the formation is 4,100 feet thick and is readily divisible into two members :

(i) a Lower Member which consists of 1,200 feet of massive, poorly bedded arenites which generally contain only a few thin siltstone beds,

(ii) an upper Member which is 2,900 feet thick and consists mostly of banded siltstones which predominate over beds of arenite. The arenites of this member are similar in all respects to those of the Lower Member.

Near the top of the formation occur conglomerate lenses which vary markedly in size. The two largest, one mile south of Mount


GEOLOGICAL MAP OF THE
CANOWINDRA EAST AREA
½ 0 1
Scale in miles
TN MN
LEGEND
THRUST
Creek
Canomodine
Rockdale
The Glen


GEOLOGICAL MAP OF THE
CANOWINDRA EAST AREA
½ 0 1
Scale in miles
TN MN
LEGEND
Recent alluvium
Tenandra Formation
Belubula Shale
Ghost Hill Formation
"Upper" Avoca Valley Shale
Canowindra Porphyry
"Lower" Avoca Valley Shale
Cudal Group
Millambri Formation
Rockdale Formation
Canomodine Limestone
Cargo Andesite
Geological Boundaries
Position accurate
" approximate
" inferred
Bedding Attitude
Inclined
Vertical
Overturned
Horizontal
Faults
Position accurate
" approximate
" inferred
Folds
Anticlines
Position accurate
" approximate
Synclines
Position accurate
" approximate
G - Graptolite localities
L - Limestone "
The Glen
Rockdale
Canomodine
Canomodine Ck
Cranky Rock
CRANKY ROCK ANTICLINE
Belubula
Millambri
CANANGLE THRUST
Canangle Creek
MOUNTAIN CREEK THRUST
River
Avoca Valley
Liscombe Pools
Liscombe Pools Creek
COLUMBINE
Canowindra Creek
Jack's Creek
Emu Creek
Canowindra

View homestead and one mile north of Liscombe Pools homestead, are about a mile long. Smaller lenses occur at the same horizon around the Cranky Rock Anticline where they range from 20 to 50 yards long. The conglomerate is composed of well rounded pebbles and cobbles of intermediate volcanic rocks (mostly andesites) set in a matrix of arenite which is the same as that occurring elsewhere in the formation.

At a stratigraphic horizon similar to that of the conglomerate bodies, at several localities, occur limestone lenses which contain *Favosites* sp., *Heliolites* sp., *Halysites* sp., *Zaphrentis* sp., and *Stromatoporidae*.

The siltstones and arenites of this formation are composed of the same minerals, though proportions differ. The silts always contain more carbonaceous matter than the arenites.

In hand specimen the arenites are blue-grey in colour, massive, hard and show an even texture. They frequently contain fragments of siltstone. In thin-section they are seen to have a fairly simple and constant mineralogy consisting of plagioclase and pyroxene grains set in a fine silty or clayey matrix together with numerous intermediate volcanic rock fragments. Hornblende grains are often present, biotite is less so and detrital quartz is notably lacking.

The plagioclase and pyroxene grains occur, in most cases, as either euhedral grains or angular fragments which show some crystal outline. The plagioclase is nearly always albite and the pyroxene is augite.

The arenites are not wholly made up of detrital minerals. Diagenetic prehnite and carbonate occur replacing both grains and matrix. These minerals are accompanied by small amounts of epidote and a few narrow and sinuous quartz veins. No pumpellyite has been found in the greywackes of the Millambri Formation.

Sedimentary structures are very common in this formation, the most widely developed being graded bedding, a feature which is seen in all but the uppermost part of the formation.

Small scale slump structures and unidirectional current bedding are common and occur associated with load casts, small scale normal faults and clastic dykes.

The sedimentary structures, taken with the poorness of sorting and the nature of the matrix of the arenites, suggest that deposition occurred from turbidity currents in a deepwater environment (Kuenen and Carozzi, 1953). These observations apply to all but the uppermost part of the formation (above the conglomerate-limestone horizon), where no graded bedding has been observed. This suggests the uppermost part may have been deposited in a shallow water environment. The sediments of the lower part of the formation are greywackes in the sense of Packham (1954).

The mineralogy of the Millambri Formation points to its being derived from a terrain consisting essentially of andesitic rocks. The current bedding and current ripple marks indicate that this terrain lay to the north-east of the area examined.

The Millambri Formation is characterized by a lack of shelly fauna except near the very top where *Linguella* sp. are common.

Graptolites have been found near the top of the formation at three localities near Liscombe Pools Creek. To the north of Liscombe Pools homestead *Glyptograptus tamariscus* occurs whilst near the very top of the formation occur fragments of *Climacograptus hughesi* and *Monograptus* sp. (identifications by Dr. G. H. Packham). This latter occurrence defines the top of the formation to lie in the lower Llandovery (lower Keilorian of Thomas, 1960).

The Cudal Group

The Cudal Group is a new name which has been erected to take the place of the " Cudal Shale " of Stevens (1951, 1954). The Group contains four formations and represents sedimentation from lowermost Silurian to uppermost Silurian or perhaps even Lower Devonian.

Avoca Valley Shale

The Avoca Valley Shale overlies the Millambri Formation and as such occurs as two distinct outcrops within the area examined—as a thin crescent around the Cranky Rock Anticline and as an elongate north-south trending strip to the east of the area in which the beds generally dip to the west at moderate to high angles.

The formation has been divided for convenience of reference into two units, the distinction being based upon stratigraphic position with respect to the Canowindra Porphyry which occurs within the formation over much of its outcrop.

" Lower " Avoca Valley Shale

The type section of the lower unit is in Licking Hole Creek south of Liscombe Pools homestead where it is 340 feet thick and is composed of red, green and brown shales which contain a prominent buff siltstone bed which is graptolitic. At the type section immediately below the contact with the Porphyry in the

red-brown shales occur numerous spherical concretions which are up to 10 inches across. Where this unit outcrops around the Cranky Rock Anticline exactly the same units are present.

In thin-section all the shales of this unit are seen to contain detrital quartz, feldspar, white mica, haematite and carbonaceous material together with abundant clay. The presence of abundant detrital quartz contrasts with the formation stratigraphically below.

No sedimentary structures indicating direction of provenance of sediments of the lower unit have been found. It is clear, however, that the source of detritus for sediments of this unit is quite different from the source of Millambri Formation sediments.

At the end of Millambri Formation time the depositional basin was relatively shallow as evidenced by the limestone lenses with their coelenterate fauna which are found at the top of the formation. Between the Millambri Formation and the " lower " unit of the Avoca Valley Shale no unconformity exists, but there may be a small disconformity. This indicates there was no large scale shallowing of the basin between the time of deposition of the two units.

At the west of the area in the buff siltstone band graptolites have been found. *Monograptus priodon, M.* aff. *vomerinus,* ? *M. spiralis* and *Retiolites geinitizianus* indicate an upper Lower to lower Middle Silurian age for the lower unit.

" Upper " Avoca Valley Shale

The upper unit of the Avoca Valley Shale occurs above the horizon of the Canowindra Porphyry and in the south of the area is present on both the eastern and western limbs of a synclinal structure. Passing northwards the western limb is terminated by the Canangle Thrust whilst the eastern limb persists northwards to the limit of the area examined. North of the Belubula River the base of the unit is missing, it being cut off by the Columbine Mountain Thrust whilst further to the north it is brought against the Cargo Andesite by another fault.

The unit consists mainly of green shales but locally red and brown shales are present. Immediately overlying the Canowindra Porphyry is a quartzo-feldspathic sandstone which contains fragments of pink garnet. The sandstones are poorly bedded and are characterized by not being uniformly developed within the unit. At the type section on the Avoca Valley property the upper unit is some 1,200 feet thick.

The sandstone occurring in this unit is composed of grains of quartz, feldspar and biotite set in a clayey matrix which always makes up less than 20% of the rock. Most grains in the sandstone are distinctly angular and in some cases euhedral bipyramidal quartz crystals are present. Light pink garnet fragments occur scattered uniformly throughout the sandstones.

The constancy of stratigraphic horizon of the garnet bearing sandstone taken with its wide variation in thickness over short distances and the similarity of the minerals present within it to those of the Canowindra Porphyry point to its being derived from the Porphyry.

Current bedding observed in the sandstone unit indicates the depositing traction currents came from a southerly direction. This may mean the Porphyry was emergent there.

The shales which make up the bulk of this unit consist predominantly of mica and chlorite-rich clay which contains numerous grains of quartz. Within the shales occur many thin bands of sandstone all of which are less than 6 inches wide. These bands are generally lenticular over short distances and frequently show current bedding and basal sandstone deformation.

Small scale slump structures present in the sandy bands have a southerly component of movement and may indicate the sea floor had a southerly component of slope at the time of deposition of the Avoca Valley Shale.

Near the top of the unit fossiliferous limestone lenses are common. The fauna contained within them is the same as that in the limestone lenses of the overlying Ghost Hill Formation. The sedimentary structures and the presence of the limestone lenses indicates that this unit was deposited in a shallow water environment. The basin appears to have been shallowing since Millambri Formation time and was probably shallowest at the time of deposition of the Ghost Hill Formation.

Stevens (1952, 1954) reports *Monograptus* cf. *dubius* from shales within this unit. The age of this unit is difficult to ascertain, but considering information gained from the overlying formations, it seems at least part of it is Wenlockian (Eildonian of Thomas, 1960).

Ghost Hill Formation

The Ghost Hill Formation, so named because it outcrops on Ghost Hill, a prominent feature on Millambri property, conformably overlies the

Avoca Valley Shale and as such occurs as a generally north-south trending strip within the area examined.

The formation consists predominantly of tuffaceous arenite and tuffaceous arenaceous siltstone in which frequently occur lenses of limestone. To the base of the formation occurs tuffaceous shales which contain graptolites, coelenterates and shelly fossils.

At the type section on the southern bank of the Belubula River the formation is 450 feet thick but away from here it thins rapidly. The formation could not be recognized in the south western part of the area. This may be due either to the very poor outcrop or to its not being developed there.

The tuffs are composed of grains of quartz, plagioclase and more rarely biotite set in a silty matrix which contains numerous devitrified shards. The quartz grains are frequently embayed bipyramidal crystals. Plagioclase occurs as both angular grains and tabular crystals which are all partially kaolinized. It lies within the oligoclase composition range. Biotite, where present, is always brown and is frequently altered to chlorite. The shards are now composed of aggregates of quartz, chlorite, carbonate and zeolites.

North of Ghost Hill, within this formation, occurs an intrusive acid igneous rock which is composed of phenocrysts of quartz, plagioclase and biotite set in a fine grained quartz-rich matrix. The quartz phenocrysts of this porphyry are often bipyramidal and are frequently embayed and this, together with other mineralogical and field evidence, suggests the tuffs occurring in this formation may be derived from similar porphyry plugs which intruded and broke through the sedimentary cover.

The presence of numerous limestone lenses and of a shelly and coelenterate fauna suggests deposition probably occurred in a shallow water environment.

The limestone lenses contain a varied fauna which consists of *Favosites* sp., *Heliolites* sp., *Tryplasma* sp., Pentamerid and Spiriferid brachiopods, crinoid stems and stromatoporids. Near Ghost Hill occur specimens of *Monograptus dubius* which indicate a Middle-Upper Silurian age for part of the formation.

Belubula Shale

The Belubula Shale conformably overlies the Ghost Hill Formation and outcrops as a narrow north-south trending strip extending from the south of the area about nine miles north. It also outcrops in the south-west of the area where it is faulted against sediments of the Tenandra Formation.

The formation is named after the Belubula River which passes through it. The type section is located about a quarter of a mile west of the Avoca Valley homestead where it is about 700 feet thick and is composed of brown, red and grey shales. South of the type section near the Canowindra road the formation is composed entirely of red and buff siltstones. These are made up of minute angular quartz grains set in a clayey matrix which contains abundant fine white mica. Biotite is rarely present, and when so is always detrital.

The sediments of this formation give little clue as to the environment of deposition but the absence of limestone, in contrast to the formation stratigraphically below, may reflect a deepening of the basin near the end of the Ghost Hill Formation time.

The lowest units in the formation contain the small brachiopod *Sowerbyella*. *Monograptus* aff. *bohemicus* has been found to the south of the type section and suggests an Upper Silurian age for the Belubula Formation though precise dating is not possible.

Tenandra Formation

The Tenandra Formation, so named because it lies in the Parish of Tenandra, conformably overlies the Belubula Shale and outcrops as a north-south trending belt which extends from the south of the area north to Canomodine homestead where it is folded to be then truncated by the Canangle Thrust. The Tenandra Formation is the uppermost Palaeozoic unit within the area examined and is composed of 1,200 feet of interbedded siltstones, arenites and shales. To the north of the type section in Emu Creek the upper part of the formation is missing, it having been truncated by the Canangle Thrust.

The shales occurring in this formation are similar mineralogically to shales occurring in lower formations. They are composed of angular grains of quartz and feldspar (generally less than $0 \cdot 02$ mm across) set in a clayey matrix in which white mica flakes are always present.

The arenites of this unit are generally resistant to weathering and show out strongly on air-photographs. They have plagioclase as the dominant component but quartz is always present. The plagioclase is oligoclase-andesine and occurs as either angular grains or as euhedral laths. Quartz occurs as angular grains or as embayed bipyramidal crystals. Hornblende

and biotite are common minor detrital minerals. The matrix of these rocks is silty and always contains abundant fine quartz and plagioclase grains. Epidote is a frequent constituent of the matrix and often rims grains but never appears to replace them. The epidote is interpreted as being detrital. In some arenites the matrix is composed almost entirely of green chlorite.

Minor slump structures and basal sandstone deformation occur at several localities within the formation. Their attitude indicates the sea floor probably sloped north-south at the time of slumping. Current bedding observed indicates that transporting currents came from a southerly direction.

No fauna whatever has been found in this formation and this makes it impossible to assign an accurate age for it. It does seem possible, however, that the Tenandra Formation may range from high in the Silurian into the Lower Devonian.

Post Tenandra Formation Deposits

No upper Devonian sediments occur on the area examined but they are present adjacent to the eastern boundary, to the east of the Columbine Mountain Thrust. No Tertiary lavas occur in the area.

The deposits of river gravel and other alluvium occurring within the area are probably of Quaternary age. The principal deposits of gravel, sand and silt occur along the Belubula River where, especially in the west of the area, wide river flats occur. Tracts of alluvium also occur in some of the larger tributary creeks, notably Canomodine Creek, Liscombe Pools Creek and Licking Hole Creek.

Canowindra Porphyry

The Canowindra Porphyry is the name given to the quartz-feldspar-biotite porphyry, characterized by the presence of sparsely distributed pink garnets, which outcrops extensively in the Canowindra area. It was named and defined by Stevens (1950, 1954) who interpreted it as being intrusive into unconsolidated sediments, but more detailed work has shown that such an interpretation leaves important considerations unanswered in the area examined. Within this area the porphyry occurs as four distinct masses all of which have their lower contact at the same stratigraphic horizon. The upper contact, because of poor outcrop, is more difficult to deal with, but it appears to be conformable.

Lying directly on the porphyry within the Avoca Valley Shale occurs a garnet bearing sandstone which varies widely in thickness over short distances along strike and contains only the minerals found in the porphyry. Moreover, these minerals show exactly the same minor features as corresponding minerals in the porphyry—they are similar in size, habit, alteration and composition. The garnet in the sandstone is identical with that found in the porphyry. (Refractive Index $1 \cdot 800 \pm 0 \cdot 002$, cell edge $11 \cdot 540$Å$\pm 0 \cdot 005$Å). If these sandstones are derived from the porphyry, and considering the constant horizon of the base of the porphyry, then it seems that the porphyry is better regarded as extrusive rather than intrusive.

Columnar jointing is common near the base of the porphyry but no flow banding has been observed in the area examined. Flow banding is not prominent in thin-section.

The porphyry is a holocrystaline porphyritic rock which consists of euhedral quartz, plagioclase and biotite phenocrysts set in a fine grained chloritized groundmass. Almandine garnet is a constant accessory mineral which may or may not be associated with any of the numerous xenoliths present. Quartz phenocrysts are frequently euhedral but most are resorbed and many are deeply embayed. Plagioclase phenocrysts are always more or less altered but fresh phenocrysts have a composition near An_{30}. Biotite phenocrysts are never fresh, they being replaced by chlorite which is often accompanied by epidote and sphene.

The groundmass is composed of aggregates of fine anhedral interlocking quartz–feldspar grains and minor biotite and chlorite. Chlorite is a constant and characteristic mineral.

Garnet occurs as large anhedral crystals within the porphyry and as xenoblasts within some xenoliths contained in the Canowindra Porphyry.

Xenoliths are plentiful in the porphyry and are of two main types:

(i) those derived from the Silurian country rock,

(ii) those not derived from rocks occurring within the area examined.

Those derived from the country rock have suffered little contact metamorphism. Such xenoliths are indurated but show no significant reorganization and have undergone metamorphic effects similar to that of the shales underlying the porphyry.

It is the xenoliths which do not come from the country rocks which are most common.

These are all hornfelsic and show no foliation. Three types are recognised:

(i) an epidote–plagioclase–biotite–quartz–(garnet) assemblage,
(ii) a quartz–plagioclase–biotite (epidote–garnet) assemblage,
(iii) a predominantly quartz–feldspar assemblage with minor epidote and garnet.

The garnet of these xenoliths is almandine and frequently contains numerous needles of sillimanite, a fact which suggests they may be relics preserved in xenoliths derived from a high grade regionally metamorphosed terrain. The assemblage almandine-sillimanite would be expected from rocks of high alumina content, but as now seen they are rich in calcic minerals-epidote, calcic plagioclase and sphene. These calcic-rich minerals indicate a change in the bulk composition of the original alumina-rich xenoliths.

Garnets which occur as " phenocrysts " in the porphyry are of two types. One contains sillimanite needles and has been interpreted as being derived from the high grade xenoliths. The other has no sillimanite needles and may either be derived from xenoliths (where sillimanite-free garnets do occur) or be pyrogenetic (Edwards, 1936).

A characteristic of the Canowindra Porphyry is the virtual lack of contact metamorphic effects with the sediments of the country rocks. The shales immediately underlying the porphyry are indurated and are frequently traversed by networks of thin quartz veins. Shales close to the contact are often " spotted " and in thin-section such spotting is due to aggregations of chloritic minerals. Spots such as these are well known in the lowest grades of thermal metamorphism in argillaceous sediments. From these considerations it appears certain that the Canowindra Porphyry was extruded at a fairly low temperature. The temperature, however, cannot be estimated but it appears to be consistent with those prevailing at the lowest grade of the albite epidote hornfels facies.

Two miles south of the south-west corner of the area examined occurs the Cowra Granodiorite (Stevens, 1952). This is an elongate body of some 20 miles in exposed length which is intrusive into Palaeozoic sediments and possibly even into the Canowindra Porphyry. Several unusual features common to both the Granodiorite and the porphyry suggest genetic ties between the two. The porphyry is characterized by the presence of numerous xenoliths, a feature which is also apparent in the Cowra Granodiorite.

The Granodiorite also contains red garnets; Stevens (1952) states: " . . . another notable feature of the Cowra Intrusion is the occurrence of abundant red garnets which seem to be associated with numerous xenoliths ". Two garnets from separate xenoliths in the Cowra Intrusion were found to have cell dimensions and refractive index the same as garnets from the Canowindra Porphyry.

Strong evidence supporting the genetic ties is given by chemical analyses of the Granodiorite and the porphyry (in Stevens, 1952). The analyses are strikingly similar and when this fact is considered with the similarities outlined above it must be suggested that the two rocks may be consanguineous.

The xenoliths of the Cowra Granodiorite are all at a distinctly higher grade than those of the porphyry and if the two bodies were originally derived from the same magma this may mean that the porphyry was maintained at a relatively higher level and at a lower temperature than the Granodiorite.

Structural Geology

Within the area examined the rocks have been folded to produce a structure which is essentially a syncline flanked by anticlines. The dominant structural feature is the Cranky Rock Anticline (Stevens, 1954) which controls outcrop over about two thirds of the area. It has an axis which trends north-south and plunges to the south at about 25°.

The Cranky Rock Anticline is separated, to the east, from the syncline by the Canangle Thrust, a structure which results in the western limb of the syncline being missing over much of the area examined. The syncline closes at the south of the area near the Canowindra–Walli road and again in the north near Canomodine homestead to define an elongate basin structure which is truncated to the west by the Canangle Thrust.

In the east of the area, south of the Belubula River an anticline is present but its eastern limb is truncated by the Columbine Mountain Thrust. This thrust was named by Stevens (1950, 1954) who has traced it along strike for over 20 miles. It has for much of its length brought Lower Palaeozoic rocks into contact with Upper Devonian–Lower Carboniferous sediments.

The Canangle Thrust, like the Columbine Mountain Thrust, is a north-south trending feature which dips to the west at a moderately high angle. Both thrusts have a throw which may be up to 1,500 feet in places. The Canangle

Thrust dies out rapidly to the south of the area but paucity of outcrop makes mapping unreliable here.

The only unconformity recognised in the area occurs above the Canomodine Limestone. This is a gentle one and appears not to be related to any of the major orogenic cycles which affected the Tasman Geosyncline.

No unconformity exists between Upper Ordovician and Lower Silurian sediments. The Millambri Formation represents sedimentation continuous from Upper Ordovician to Lower Silurian times. At the end of Millambri Formation time there is, however, a distinct change in sedimentary provenance. This fact considered with the conglomerate lenses near the top of the Millambri Formation may reflect the effects of the Benambran Orogeny in the source area. The presence of limestone lenses in or near the conglomerate horizon is interpreted as being due to shallowing of the depositional basin. This may be due either to infilling of the basin or to uplift of the basin by tectonic forces. Although the former may be important it is the latter which seems to best account for the observed facts. This shallowing is the only result of the Benambran Orogeny observed in the area studied.

As no Upper Devonian sediments occur within the area it is not possible to directly define the relationship between them and the Silurian sediments of the area. To the east of the area, however, Upper Devonian and Lower Carboniferous sediments unconformably overlie Middle and Upper Ordovician sediments.

The Silurian formations in the area examined were deposited in the Cowra Trough (Packham, 1958) which Packham considers to have been folded not at the end of the Silurian Period but somewhat later in the Lower Devonian as either a late result of the Bowning Orogeny or as an early result of the Tabberabberan Orogeny.

To the east of the area the Upper Devonian–Carboniferous sediments are gently folded. Such folding is probably a result of the Kanimblan Orogeny which presumably also folded the area studied.

Acknowledgements

I wish to thank Professor C. E. Marshall in whose department the work was carried out. I am indebted to Drs. Vallance and Packham for their generous help whilst the study was in progress. I wish also to thank Dr. I. M. Threadgold who has been a constant inspiration and who introduced me to the X-ray techniques. My thanks are also due to Miss J. Forsyth who produced the map.

The residents of the area deserve my special considerations. I am especially grateful to Mr. R. Latham and Mr. and Mrs. Ward of "Millambri", Mr. and Mrs. H. McLaren of "Liscombe Pools" and Mr. and Mrs. Brown of "Avoca Valley" for the considerable help they afforded me.

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Department of Geology and Geophysics,
University of Sydney,
Sydney.

Report of the Council for the Year Ended 31st March, 1965

Presented at the Annual and General Monthly Meeting of the Society held 7th April, 1965, in accordance with Rule XXVI.

At the end of the period under review the composition of the *membership* was 359 members, 14 associate members and 9 honorary members ; 15 new members were elected. Six members and 2 associate members resigned ; the names of 2 members and 1 associate member were removed from the list of members in accordance with Rule XVIII.

It is with extreme regret that we announce the *loss by death* of :

Prof. Victor A. Bailey (elected 1924),
Mr. John R. Bardsley (elected 1919),
Mr. Frederick A. Coombs (elected 1913),
Mr. Kenneth P. Forman (elected 1932),
Father Anthony G. Fynn (elected 1959),
Prof. Jack M. Somerville (elected 1959).

Nine monthly meetings were held. The abstracts of all addresses have been printed on the notice paper. The proceedings of these will appear later in the issue of the " Journal and Proceedings ". The members of the Council wish to express their sincere thanks and appreciation to the nine speakers who contributed to the success of these meetings, the average attendance being 28.

The *Annual Social Function* was held on 25th March at the Sydney University Staff Club and was attended by 34 members and guests.

The Council has approved the following *awards* :

The *Clarke Medal* for 1965 to Dr. M. Josephine Mackerras, M.Sc., M.B., M.C.P.A., of C.S.I.R.O., Division of Entomology, Canberra.

The *Society's Medal* for 1964 to Mr. F. D. McCarthy, Principal Australian Institute of Aboriginal Studies, Canberra.

The *James Cook Medal* for 1964 to Dr. M. R. Lemberg, D.Phil., F.R.S., F.A.A., of the Institute of Medical Research, Royal North Shore Hospital, St. Leonards.

The *Edgeworth David Medal* for 1964 to Dr. Mollie E. Holman, M.Sc., Ph.D., Department of Physiology, Monash University, Victoria.

The *Archibald D. Olle Prize* for papers published in volume 97 of the " Journal and Proceedings " awarded jointly to Dr. J. Roberts, Bureau of Mineral Resources, Canberra, for his papers entitled " A Lower Carboniferous Fauna from Lewinsbrook, New South Wales " and " Lower Carboniferous Faunas from Wiragulla and Dungog, New South Wales " ; and to Mr. J. L. Griffith, for his paper entitled " On the Gibbs' Phenomenon in n-Dimensional Fourier Transforms ".

The *Liversidge Research Lecture* for 1964, entitled " Heterocyclic Chemistry and Some Biological Overtones ", was delivered by Prof. Adrien Albert, Ph.D., D.Sc., F.A.A., of the Department of Medical Chemistry, The John Curtin School of Medical Research, The Australian National University, Canberra (see " Journal and Proceedings ", vol. 98, pp. 11–22).

The Society has again received a *grant* from the Government of New South Wales, the amount being £750. The Government's interest in the work of the Society is much appreciated.

The Society's *financial statement* shows a surplus of £593 5s. 6d., due to the sale of library assets.

The *New England Branch* of the Society met six times during the year and the proceedings of the Branch follow.

The President represented the Society at the Commemoration of the Landing of Captain Cook at Kurnell ; attended the Reception to the Right Honourable Lord Bowden of Chesterfield, Minister of State for Education and Science in the British Government and, during the visit of His Royal Highness The Duke of Edinburgh, the President was a guest at a State Luncheon and attended the First Dunrossil Lecture which His Royal Highness delivered.

The President attended the Annual Meeting of the Board of Visitors of the Sydney Observatory.

On 14th October, the President and the Honorary Secretary waited on His Excellency the Governor of New South Wales.

We congratulate Mr. F. D. McCarthy, a former President of the Society, on his appointment as Principal of the Australian Institute of Aboriginal Studies ; A/Prof. R. L. Stanton, on his award of a Royal Society Bursary and Prof. N. H. Fletcher on the award of a Nuffield Dominion Travelling Fellowship in Natural Sciences.

The Society's representatives on the *Science House Management Committee* were Mr. H. F. Conaghan and Dr. A. H. Low.

Five parts of the " *Journal and Proceedings* " have been published during the year.

As from 1st January, 1965, the cost of publishing the " Journal and Proceedings " rose by 10%.

Council held 11 ordinary meetings and attendance was as follows : Mr. J. W. Humphries 10 ; Mr. C. L. Adamson 4 ; Mr. H. H. G. McKern 8 ; Mr. W. H. G. Poggendorff 6 ; A/Prof. W. B. Smith-White 7 ; Dr. A. H. Low 11 ; Dr. A. A. Day 9 ; Mr. H. F. Conaghan 11 ; Dr. Ida A. Browne 7 ; Dr. R. Gascoigne 4 ; Mr. H. G. Golding 1 (absent on leave for 8) ; Prof. A. Keane 6 ; Prof. R. J. W. Le Fevre 2 ; Mr. J. Middlehurst 3 (absent on leave for 4) ; Mr. J. W. G. Neuhaus 8 ; Dr. A. Reichel 7 ; A/Prof. R. L. Stanton 2 (absent on leave for 5) ; Dr. A. Ungar 4.

During the year Council held 4 Special Meetings to discuss and propose alterations to the Rules of the Society, consideration of which is nearing completion.

Back numbers of the Society's " *Journal and Proceedings* " held in the storeroom have now been cleaned, sorted and packed. Students were engaged to do this and the cost of storage expenses amounted to £169 16s. 3d.

The *Library*—Periodicals were received by exchange from 392 societies and institutions. In addition the amount of £123 2s. 0d. was expended on the purchase of 11 periodicals.

Book-binding of some of the more rare sets of periodicals has been carried out by Sydney Technical College and the Society, in appreciation, is making a permanent book-binding prize each year to the value of £10 10s. 0d.

Among the institutions which made use of the library through the inter-library loan scheme were :

N.S.W. Govt. Depts.—Dept. of Agriculture, Forestry Commission, Main Roads Dept., Mines Dept., M.W.S. and D. Board, Public Works Dept., Railway Dept., State Fisheries, Water Conservation and Irrigation Commission, Standards Association.

Commonwealth Govt. Depts.—Australian Atomic Energy Commission, Bureau of Mineral Resources, Commonwealth Acoustics, Commonwealth Forestry and Timber Bureau, C.S.I.R.O. Depts. :—Head Office, Melbourne ; Animal Genetics, Epping ; Chemical Research Laboratories, Victoria ; Coal Research Section, Ryde ; Food Preservation, Ryde ; Fisheries and Oceanography, Cronulla ; Library, Canberra ; National Standards Laboratory, Chippendale ; Textile Physics, Ryde ; Tropical Pastures, Brisbane ; Western Australia Regional Laboratories, Nedlands ; Wild Life, Canberra.

Universities and Colleges—Australian National University, Monash University, Newcastle University, New England University, New South Wales University, Queensland University, School of Public Health and Tropical Medicine, Sydney University, University of Western Australia, Wollongong University College.

Companies—Wm. Arnott Ltd., Aust. Aquitane Pty. Ltd., Aust. Coal Association, Australian Gaslight Co. Ltd., Aust. Sisalkraft Co., A.E.I. Engineering Pty. Ltd., Aust. Consolidated Industries, B.H.P. Co. Ltd., British Aust. Tobacco Co., C.S.R. Co. Ltd., Electrolytic Zinc Co. Ltd., Geigy Agricultural Chemicals, I.C.I. Ltd., Johnson and Johnson, Lysaght Ltd., Mauri Bros. and Thompson, Union Carbide Chemical Division, W. D. and H. O. Wills Ltd.

Research Institutes—Children's Hospital, Prince of Wales Hospital, St. Vincent's Hospital, Victorian State Laboratories, Bread Research Institute.

Museums—Australian Museum.

Miscellaneous—Institution of Engineers, Australia, Sydney Division ; Geological Survey of Queensland.

A. H. Low,
Hon. Secretary.

7th April, 1965.

Abstract of Proceedings, 1964

1st April, 1964

The ninety-seventh Annual and seven hundred and ninety-first General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. H. G. McKern, was in the chair. There were present 35 members and visitors.

The following were elected members of the Society : Torrence Edward Kitamura ; Arthur Wyngate Thurstan.

The Annual Report of the Council and the Financial Statement were presented and adopted.

The following awards of the Society were announced :

The Society's Medal for 1963 : Professor R. S. Nyholm, F.R.S.

The Clarke Medal for 1964 : Dr. Joyce W. Vickery, M.B.E.

The Edgeworth David Medal for 1963 : Professor N. H. Fletcher.

Office-bearers for 1964–65 were elected as follows :

President : J. W. Humphries, B.Sc.
Vice-Presidents : C. L. Adamson, B.Sc. ; H. H. G. McKern, M.Sc. ; W. H. G. Poggendorff, B.Sc.(Agr.) ; A/Professor W. B. Smith-White, M.A.

Hon. Secretaries : A. H. Low, Ph.D., M.Sc. ; Alan A. Day, B.Sc., Ph.D.

Hon. Treasurer : H. F. Conaghan, M.Sc.

Members of Council : Ida A. Browne, D.Sc. ; R. M. Gascoigne, Ph.D. ; H. G. Golding, M.Sc. ; R. J. W. Le Fevre, D.Sc., F.R.S., F.A.A. ; A. Keane, Ph.D. ; J. Middlehurst, M.Sc. ; J. W. G. Neuhaus, A.S.T.C. ; A. Reichel, Ph.D., M.Sc. ; R. L. Stanton, Ph.D. ; A. Ung, Dr.Ing.

Messrs. Horley and Horley were re-elected Auditors to the Society for 1964–65.

The retiring President, Mr. H. H. G. McKern, delivered his Presidential Address entitled " Volatile Oils and Plant Taxonomy ".

At the conclusion of the address the retiring President welcomed Mr. J. W. Humphries to the Presidential Chair.

6th May, 1964

The seven hundred and ninety-second General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. J. W. Humphries, was in the chair. There were present 24 members and visitors.

The following were elected members of the Society : Edgar David Bradley, Colin Frank Bruce and Barrie Stirling Stevenson.

The following papers were read by title only : " The Eclogite-bearing Basic Igneous Pipe at Ruby Hill near Bingara, New South Wales ", by J. F. Lovering ; " On Traces of Native Iron at Port Macquarie, New South Wales ", by F. M. Quodling ; " Lower Cretaceous Sporomorphs from the Northern Part of the Coonamble Basin, N.S.W. ", by J. Rade.

An address entitled " The International Quiet Sun Years " was delivered by Dr. R. G. Giovanelli, F.A.A., of the Division of Physics, National Standards Laboratory, Sydney.

3rd June, 1964

The seven hundred and ninety-third General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. J. W. Humphries, was in the chair. There were present 46 members and visitors.

The following were elected members of the Society : Charles Dixon Cox and Graeme Maxwell Philip.

The following papers were read by title only : " Lower Carboniferous Faunas from Wiragulla and Dungog, New South Wales ", by John Roberts ; " James Dwight Dana in New South Wales, 1839–1840 ", by Ann Mozley ; " Minor Planets observed at Sydney Observatory during 1963 ", by W. H. Robertson ; " Occultations observed at Sydney Observatory during 1962–63 ", by K. P. Sims.

An address entitled " Searching for Meteorites and Australites " was delivered by Mr. R. O. Chalmers, Curator of Minerals, The Australian Museum, Sydney.

1st July, 1964

The seven hundred and ninety-fourth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. J. W. Humphries, was in the chair. There were present 20 members and visitors.

The following were elected members of the Society : Noel Charles William Beadle ; Raymond Albert Binns.

An address entitled " The Australian High Temperture Gas-Cooled Reactor Feasibility Study " was delivered by Mr. W. H. Roberts, Deputy Director, Australian Atomic Energy Commission, Research Establishment, Lucas Heights.

5th August, 1964

The seven hundred and ninety-fifth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

A/Professor W. B. Smith-White, Vice-President, was in the chair. There were present 35 members and visitors.

The following was elected a member of the Society : Thomas Denis Rice.

An address entitled " The Philosophy *of* Science and the Philosophy *in* Science " was delivered by Dr. R. M. Gascoigne, of the School of Philosophy, the University of New South Wales.

2nd September, 1964

The seven hundred and ninety-sixth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. J. W. Humphries, was in the chair. There were present 20 members and visitors.

Warren Manser was elected a member of the Society.

An address entitled "Fossil Magnetism" was delivered by Dr. Alan A. Day, of the Department of Geology and Geophysics, the University of Sydney.

7th October, 1964

The seven hundred and ninety-seventh General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. J. W. Humphries, was in the chair. There were present 26 members and visitors.

The following were elected members of the Society: Robert Kerril Booth, John Albert McGlynn and John Alan Belmore Scott.

An address entitled "Viruses and Antibodies" was delivered by Professor S. Fazekas de St. Groth, F.A.A., of the Department of Microbiology, The John Curtin School of Medical Research, The Australian National University.

4th November, 1964

The seven hundred and ninety-eighth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. J. W. Humphries, was in the chair. There were present 16 members and visitors.

An address entitled "The Importance of Tetrapyrrolic Pigments in Biological Systems" was delivered by Dr. P. S. Clezy, of the School of Chemistry, The University of New South Wales.

2nd December, 1964

The seven hundred and ninety-ninth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. J. W. Humphries, was in the chair. There were present 25 members and visitors.

Erich Vincent Lassak was elected a member of the Society.

The following papers were read by title only: "The Mesozoic Age of the Garrawilla Lavas in the Coonabarabran-Gunnedah District", by J. A. Dulhunty; "A Note on the Stratigraphy of the Devonian Garra Beds of N.S.W.", by D. L. Strusz.

An address entitled "The Physics of Ice" was delivered by Prof. N. H. Fletcher, of the Department of Physics, University of New England.

Members of the Society, April, 1965

A list of members of the Society up to 1st April, 1964, is included in Volume **97**.

During the year ended 31st March, 1965, the following were elected to membership of the Society :

BEADLE, Noel Charles William, D.Sc., Professor of Botany, University of New England, Armidale.

BINNS, Raymond Albert, B.Sc.(Syd.), Ph.D.(Cantab.), Geology Department, University of New England, Armidale.

BOOTH, Robert Kerril, B.Sc., Dip.Ed.(Syd.), Science Teacher, 46 Jellicoe Street, Hurstville.

BRADLEY, Edgar David, M.B., B.S.(Syd.), D.O., Ophthalmologist, 107 Faulkner Street, Armidale.

BRUCE, Colin Frank, D.Sc., Physicist, 17 Redan Street, Mosman.

COX, Charles Dixon, B.Sc., 51 Darley Street, Forestville.

LASSAK, Erich Vincent, B.Sc.(Hons.), A.S.T.C., Research Chemist, 167 Berowra Waters Road, Berowra.

MANSER, Warren, B.Sc.(Syd.), L. A. Cotton School of Geology, University of New England, Armidale.

McGLYNN, John Albert, B.Sc.(Hons.), Analyst, Department of Mines, Sydney.

PHILIP, Graeme Maxwell, M.Sc.(Melb.), Ph.D. (Cantab.), F.G.S., Geology Department, University of New England, Armidale.

RICE, Thomas Denis, B.Sc., 44 Farnell Street, Gladesville.

SCOTT, John Alan Belmore, B.Sc.(Q'ld.), 28 Duncan Street, Punchbowl.

STEVENSON, Barrie Stirling, B.E.(Mech. and Elec.) (Syd.), A.M.I.E. Aust., 21 Glendower Avenue, Eastwood.

THURSTAN, Arthur Wyngate, A.S.T.C., A.R.A.C.I., Metallurgist, 99 Stoney Creek Road, Beverley Hills.

During the same period resignations were received from the following :

Annison, Ernest Frank,
Bloom, Pamela Lillian (Associate),
Coleman, Patrick Joseph,
De Lepervanche, Beatrice Joy,
Durie, Ethel Beatrix,
Fischer, Stephen,
McGlynn, John Albert (Associate),
Pickering, William Frederick.

and the following names were removed from the list of members under Rule XVIII :

Giffen, James Campbell ; Kelly, Caroline Tennant.

Financial Statement

The Honorary Treasurer's Report

The Society this year has recorded a surplus of £593 6s. 5d.

Income for the year included £626 12s. 7d., from the sale of library assets so that actually the Society operated on a deficit of £33 7s. 1d., for the twelve months. The items contributing chiefly to this deficit were cleaning and storage. Cleaning costs have risen 50% to £151 5s. 0d. owing to additional cleaning and polishing of tiles in the Society's rooms. An amount of £169 16s. 3d. was outlayed on the cleaning of the storeroom and the cleaning and packaging of the back numbers of the " Journal and Proceedings ". This outlay was essential for the preservation of the back numbers which represent a significant asset. With the exception of the installation of some wooden shelving some ten years ago, this is the first major expense on the storeroom since the Society has occupied the present quarters.

On the credit side a saving of £91 3s. 2d., as against last year has been effected on general printing. This is due to the purchase of a duplicating machine on which Council and Monthly Meeting notices, library selling lists, etc., are reproduced. The machine cost £91 13s. 0d., and has paid for itself in five months.

A Finance Committee was instituted by the Council of the Society in late 1963. The purpose of this Committee is to advise Council on all matters relating to finance and expenditure. The Committee consists of the President, the Hon. Secretaries, the Hon. Treasurer and certain members appointed by the Council. During the current year Messrs. C. L. Adamson, H. A. Donegan and Dr. A. Ungar served on this Committee.

Since the last annual general meeting, Council, following investigations and recommendations by the Finance Committee, has :—

- Purchased a duplicating machine ;
- had monthly meeting notices duplicated instead of printed ;
- obtained approval to purchase office requirements through the Government Stores Department ;
- applied for exemption from payment of Sales Tax—the application was unsuccessful ;
- had the storeroom cleaned and back numbers of the " Journal and Proceedings " cleaned and packaged ;
- approached Mr. N. S. Rishworth to act as Honorary Solicitor to the Society.

The Committee is currently investigating several other matters including the introduction of company membership, the investment of funds other than in gilt-edged securities, approaching the C.S.I.R.O. for an annual grant towards the cost of the Library, the financial structure of the other Royal Societies throughout Australia and approaching the State Government for an increase in the Government subsidy.

(Signed) H. F. CONAGHAN,
Hon. Treasurer.

7th April, 1965.

THE ROYAL SOCIETY OF NEW SOUTH WALES

BALANCE SHEET AS AT 28th FEBRUARY, 1965

LIABILITIES

1964		£ s. d.	£ s. d.
—	Accrued Expenses		500 0 0
30	Subscriptions Paid in Advance		40 8 6
89	Life Members' Subscriptions — Amount carried forward		82 19 0
	Trust Funds (detailed below)—		
	Clarke Memorial	2,053 13 0	
	Walter Burfitt Prize	1,202 6 11	
	Liversidge Bequest	696 12 3	
	Ollé Bequest	266 2 7	
4,194			4,218 14 9
29,693	Accumulated Funds		30,246 11 4
185	Employees' Long Service Leave Fund Provision		217 18 8
	Contingent Liability (in connection with Perpetual Lease).		
£34,191			£35,306 12 3

ASSETS

1964		£ s. d.	£ s. d.
2,859	Cash at Bank and in Hand		4,202 15 3
	Investments—		
	Commonwealth Bonds and Inscribed Stock—At Face Value—held for :		
	Clarke Memorial Fund	1,800 0 0	
	Walter Burfitt Prize Fund	1,000 0 0	
	Liversidge Bequest	700 0 0	
	General Purposes	4,840 0 0	
8,660			8,340 0 0
185	Fixed Deposit—Long Service Leave Fund		217 18 8
	Debtors for Subscriptions	107 7 0	
	Less Reserve for Bad Debts	107 7 0	
—			—
14,835	Science House—One-third Capital Cost		14,835 4 4
6,800	Library—At Valuation		6,800 0 0
838	Furniture and Office Equipment—At Cost, *less* Depreciation		897 1 6
13	Pictures—At Cost, *less* Depreciation		12 12 6
1	Lantern—At Cost, *less* Depreciation		1 0 0
£34,191			£35,306 12 3

TRUST FUNDS

	Clarke Memorial £ s. d.	Walter Burfitt Prize £ s. d.	Liversidge Bequest £ s. d.	Ollé Bequest £ s. d.
Capital at 28th February, 1965 ..	1,800 0 0	1,000 0 0	700 0 0	—
Revenue—				
Balance at 29th February, 1964 ..	292 4 7	164 1 4	14 0 6	223 17 7
Income for twelve months	69 3 5	38 5 7	26 15 2	42 5 0
	361 8 0	202 6 11	40 15 8	266 2 7
Less Expenditure	107 15 0	—	44 3 5	—
Balance at 28th February, 1965 ..	£253 13 0	£202 6 11	*£3 7 9*	£266 2 7

ACCUMULATED FUNDS

	£ s. d.	£ s. d.
Balance at 29th February, 1964		29,692 15 4
Add—		
Decrease in Reserve for Bad Debts ..		9 6 0
Adjustment—Subscriptions Refund ..		3 3 0
Surplus for Twelve Months		593 5 6
		30,298 9 10
Less—		
Transfer for Long Service Leave Fund Provision	25 0 0	
Adjustment—Salaries	0 3 0	
Adjustment—Subscriptions	4 4 0	
Subscriptions Written Off	22 11 6	
		51 18 6
		£30,246 11 4

Auditors' Report

The above Balance Sheet has been prepared from the Books of Account, Accounts and Vouchers of The Royal Society of New South Wales, and is a correct statement of the position of the Society's affairs on 28th February, 1965, as disclosed thereby. We have satisfied ourselves that the Society's Commonwealth Bonds and Inscribed Stock are properly held and registered.

HORLEY & HORLEY,
Chartered Accountants.

Registered under the Public Accountants
Registration Act, 1945, as amended.

Prudential Building,
39 Martin Place, Sydney,
25th March, 1965.

(Sgd.) H. F. CONAGHAN,
Honorary Treasurer.

INCOME AND EXPENDITURE ACCOUNT

1st MARCH, 1964, to 28th FEBRUARY, 1965

1964					£ s. d.
11	Annual Social				31 7 9
38	Audit				37 16 0
50	Branches of the Society				25 0 0
104	Cleaning				151 5 0
45	Depreciation				47 17 6
69	Electricity				50 5 1
4	Entertainment				7 5 6
35	Insurance				36 10 1
147	Library Purchases				136 3 5
161	Miscellaneous				195 5 2
131	Postages and Telegrams				147 17 7
	Printing—Journal—				
		Vol. 97, Parts 2–5	£1,088 3 0		
		Binding	37 10 0		
		Reprints	281 6 9		
		Cotswold Collotype	131 11 9		
		Postages	69 9 4		
		Provision for Vol. 97, Parts 6A and 6B	500 0 0		
				2,108 0 10	
	Less—				
		Sale of Reprints	956 7 6		
		Subscriptions (to Journal)	288 18 4		
		Back Numbers	102 6 0		
		Refund Postages	17 18 8		
409		Transfer — Clarke Memorial Lecture	107 11 0		
				1,473 1 6	
					634 19 4
187	Printing—General				95 9 10
1,038	Rent—Science House Management				1,196 4 0
64	Repairs				13 13 6
1,426	Salaries				1,501 7 0
—	Storage Expenses				169 16 3
39	Telephone				41 10 10
2,212	Surplus for the Twelve Months				593 5 6
£6,170					£5,112 19 4

1964		£ s. d.
955	Membership Subscriptions	980 3 6
7	Proportion of Life Members' Subscriptions	6 6 0
750	Government Subsidy	750 0 0
2,024	Science House Management—Share of Surplus	2,362 3 7
234	Interest on General Investments	229 13 8
2,193	Sale of Library Assets	626 12 7
4	Donations	—
3	Sundry Receipts	8 0 0
—	Publication Grants Received	150 0 0
£6,170		£5,112 19 4

Section of Geology

CHAIRMAN : H. G. Golding, M.Sc. HON. SECRETARY : D. S. Bridges.

Abstract of Proceedings, 1964

Five meetings were held during the year, the average attendance being about 16 members and visitors.

March 20th (*Annual meeting*) : *Election of Office-bearers* :—Chairman : Mr. H. G. Golding ; Hon. Secretary : Mr. D. S. Bridges.

Address by Mr. A. J. Gourlay : " Some Aspects of the Geology of Portuguese Timor ".

" The address commenced with a brief outline of the history of geological investigation on the island. It was explained that, while many of the early investigations had for their main objective the collection of fossil material, the intricate tectonics of the island were also realised. It was concluded that the tectonics were of the alpine type, with thrust sheets resting on an intensely folded autochthonous substratum—giving rise to two stratigraphies differing widely—one appropriate to each complex. Investigations from 1958 found the overthrust theory to be valid only up to Cretaceous-Eocene time, and only Permian rocks were found to be allochthonous.

The stratigraphies of both the autochthonous and allochthonous complexes were outlined, and illustrated by a generalised stratigraphic column, showing average thicknesses, types of facies, and brief lithological descriptions. The autochthonous range in age from pre-Permian to Recent, all intervening ages being represented, and the overthrust consists of the Permian Upper and Lower Maubisse Formations. Attention was drawn to the similarities of many of the formations present to those throughout the Tethyan environment, extending from Europe through southern Asia to the East Indies, among these being molasse, flysch and block clay formations. It was seen that the facies present are characteristic of regions of both high and low relief, and that these conditions alternated from pre-Permian time to the present day.

The address was concluded by some observations on the petroleum prospects of Timor. Possible source rocks in the Upper Cribas (Permian), Aitutu (Triassic) and Viqueque (Upper Miocene) Formations were indicated. Potential reservoir rocks were said to exist in the Cretaceous, in the Viqueque Formation and in the Coastal Plain (Plio-Pleistocene) Deposits. It was thought also that the folded and fractured Bedded Limestone Group of the Aitutu Formation has good secondary porosity. The possibility of anticlinal traps in the Cribas and Aitutu Formations, or of unconformity traps between the two Formations, or in the Aitutu Formation near the Tertiary onlap surface, was considered. Strong tectonic movements, however, might be detrimental to the forming of pools of large size ".

May 15th : *Address by Mr. K. R. Glasson* : " Some Observations on Overseas Ore Deposits ".

" Four main areas were considered :—

1. The association of tin mineralisation and structural features near the granite-slate contact at South Crofty in Cornwell. Here, certain features common to the Mount Bischoff deposit in Tasmania were noted, especially in relation to the porphyry dykes.

2. In Ireland, the recently-discovered Tynagh lead deposit was compared with the well-known lead-zinc-copper mineralisation at Silvermines. Despite the strong stratigraphic control exhibited in both areas implying perhaps a syngenetic origin for the mineralisation, the bulk of the evidence is that the ore in its present position in both areas is controlled by structural features and an epigenetic origin could still be postulated regardless of the non-outcrop of granite.

3. In British Columbia, the Craegmont copper deposit was discussed in terms of the use of geochemistry and geophysics in exploration. This deposit has only recently gone into full production, but presents interesting features in terms of wall-rock alteration.

4. The Pima ore-body—a porphyry copper type in Arizona—was discussed briefly in relation to its geological setting ".

July 17th : *Address by Dr. A. D. Albani* : " Geology of the Northern Apennines, Italy ".

Dr. Albani dealt with the stratigraphy of the autochthon, with the allochthonous cover of the " argille scagliose " (i.e. liter. " scaly clays "), and with the tectonics of the autochthon. Discussing the stratigraphy of the autochthon, three formations were particularly stressed : the " anhydrite series ", the " brecciole nummulitiche " and the " macigno " formation. The " macigno " and the " brecciole " were regarded as the product of the final settling down of turbidity currents. The Migliorini's basic ideas of the " composite wedge " as to primary tectonics have been illustrated, as well as the orogenic " landslips " which are at the base of the formation of the allochthonous cover. Applications of the " composite wedge " to the Northern Apennines were discussed and illustrated. Finally, particular stress was laid upon the nature and age of the " exotics " which are included in the allochthon.

September 18th : *Address by Mr. Jack Taylor* : " The Collection and Cutting of Gemstones ".

Mr. Taylor commenced by discussing the history of the uses of some of the more common gemstones, including quartz, chalcedony, agate, opal, sapphire, emerald, ruby, garnet, etc., and showed slides of the excellent ornaments produced with these gemstones in ancient times. Slides showing many recent cut and polished specimens of various gemstones were shown and explained. Of particular interest were the fine samples of Australian black opal displayed.

Mr. Taylor then discussed the geographical distribution of many Australian gemstone areas, and referred to the establishment of new Lapidary Clubs in many centres in New South Wales and Queensland, and to the aims and personnel of these Clubs. The address concluded with a discussion of the various methods

by which raw gemstones could be cut and polished to produce stones suitable for use in ornaments.

November 27th: *Symposium on* " Stratigraphic Problems on the Edge of the Great Artesian Basin ".

Three speakers participated :—

1. *Mr. M. Hind* (Water Conservation and Irrigation Commission) :—

" The Great Artesian Basin has an area of about 600,000 sq. miles and a perimeter of about 4,600 miles. In N.S.W. the maximum thickness of Mesozoic strata is about 7,000 ft.; this occurs in the Moree Trough near the Queensland border. An overthrust fault in the basement forms the eastern margin of this trough, but it has not disturbed the Mesozoic sequence.

" The basement of the Basin consists mainly of metamorphic rocks, but granites occupy quite large areas in the floor of the Coonamble Lobe and the Eulo Shelf. Permian strata underlie the eastern part of the Coonamble Lobe, but they wedge out rapidly to the west.

" Temperature gradients are lowest in the east where there is a great thickness of sedimentary strata. They rise steadily towards the west from 1·25°F/100 ft. in the Moree Trough to more than 3·5°F/100 ft. on the Eulo Shelf and in the western part of the Bulloo Embayment. There appears to be a definite relationship to the occurrence of granitic basement, either because of the better heat conductance of the granites, or because of radioactivity.

" The Mesozoic sequence includes Triassic, Jurassic, and Cretaceous sediments. In N.S.W. the Triassic rocks appear to be confined to the eastern part of the Coonamble Lobe. The Jurassic strata are more widespread and cover the deeper parts of the Coonamble Lobe and possibly the Lila Trough, whilst the Cretaceous overlap the Jurassic except at the eastern margin, and, with this exception, are believed to occupy the full area of the Basin in this State ".

2. *Dr. J. A. Dulhunty* (University of Sydney) :—

" There is now no doubt regarding the correlation of Mesozoic formations throughout the districts between Dubbo and Gunnedah. Outcrops of the Jurassic Pilliga Sandstone and Purlawaugh Beds, with underlying Triassic sediments, have been mapped throughout the region. Some uncertainty still remains regarding the exact relations between the Triassic sections in the Sydney and Oxley Basins and in the south-eastern margin of the Great Artesian Basin.

" Recent investigations in the Gunnedah-Coonabarabran district have established the fact that the Garrawilla Lavas, as originally defined by E. J. Kenny, are in fact extrusive and interbedded between the Triassic Napperby Beds and the Jurassic Purlawaugh Beds. Furthermore, it has now been established that trachyte flows, extruded from alkaline plugs in the Mullally-Tambar Springs-Rocky Glen district, are interbedded with the Garrawilla Lavas and are of Mesozoic age ".

3. *Mr. L. R. Beddoes and Mr. P. T. Stafford* (Esso Exploration Australia, Inc.) (delivered by Mr. L. R. Beddoes) :—

" The Surat Basin has a total maximum section of more than 27,000 feet of Permian and Mesozoic sedimentary rocks. These rocks consist mainly of marine to continental shale, siltstone and sandstone. Lesser amounts of coal, conglomerate and tuff are present. The historical geology of the Basin and the stratigraphy of each formational unit is discussed in general terms.

" One of the main problems as concerns stratigraphy in the Surat Sub-basin is the varying nomenclature used by different workers. It is recommended that in so far as is practical, stratigraphic nomenclature be standardised throughout the Basin. If this is done, then the reader of geological literature can better relate local areas to the regional geological picture ".

Annual Report of the New England Branch of the Royal Society of New South Wales

Officers for the year were :—

Chairman :	J. H. Priestley,
Secretary–Treasurer :	R. L. Stanton,
Committee members :	P. D. F. Murray,
	R. H. Stokes,
	N. H. Fletcher,
	N. W. Taylor,
	B. A. G. Plummer.

Six meetings were held as follows :

9th April, 1964 : Professor N. H. Fletcher, Department of Physics, University of New England, on " Ice ".

21st May, 1964 : Dr. L. E. Samuels, Superintendent of the Metallurgy Division, Department of Supply, on the " Nature of metal surfaces ".

3rd August, 1964 : Professor B. J. Mason, Department of Cloud Physics, Imperial College, University of London, on " Recent developments in the physics of clouds, rain and snow ".

21st September, 1964 : Professor R. H. Stokes, Department of Chemistry, University of New England, on " Why does salt dissolve in water ".

22nd October, 1964 : Dr. D. B. Lindsay, Department of Biochemistry, University of New England, on " How much insulin is there in blood ".

13th November, 1964 : Mr. Rowan Nicks, Senior Thoracic Surgeon, Royal Prince Alfred Hospital, on " The evolution of thoracic and cardiac surgery ".

Financial Statement

	£	s.	d.
Credit balance of account at University of New England Branch, Commercial Banking Company of Sydney, as at 25th March, 1964	£65	1	0
Remittance from the Royal Society of New South Wales, 3rd July, 1964 ..	£25	0	0
Interest to 30th June, 1964		19	9
Interest to 30th December, 1964	£ 1	4	8
Making a Total of	£92	5	5
Expenditure			
Reimbursement of R. L. Stanton for expenditure on Society's behalf (purchase of crockery, duplication, etc.) 2nd July, 1964	£10	10	0
Duplicating charges by University of New England		10	5
Honorarium for Secretarial Assistance	£ 3	3	0
Total	£14	3	5
Leaving a Balance of	£78	2	0

R. L. Stanton,

Hon. Secretary–Treasurer.

31st March, 1965.

Obituary, 1964-1695

Victor A. BAILEY (1924)
John R. BARDSLEY (1919)
Frederick A. COOMBS (1913)
Kenneth P. FORMAN (1932)
Anthony G. FYNN (1959)
Jack M. SOMERVILLE (1959)

Medals, Memorial Lectureships and Prizes

1964	Max Rudolph Lemberg, D.Phil., F.R.S., F.A.A.	
1965	M. Josephine Mackerras, M.Sc., M.B., M.C.P.A.	
1964	Frederick David McCarthy, Dip.Anthr.	
1964	Mollie E. Holman, M.Sc., Ph.D.	
1964	Adrien Albert, Ph.D., D.Sc., F.A.A.	
1964	James Langford Griffith, B.A., M.Sc. John Roberts, Ph.D.	Joint Award

Victor Albert Bailey, D.Phil.(Oxon.), F.A.A., Emeritus Professor, University of Sydney, was born in Egypt on 18th December, 1895, and died at Geneva, Switzerland, on 7th December, 1964.

After graduation from Queen's College, Oxford, he became a Demonstrator under Professor J. S. Townsend whose strong recommendation led to his appointment as Associate Professor of Physics in Sydney. He embarked on an intensive programme in this field, publishing many papers. In 1936 he was appointed Professor of Experimental Physics, and in 1953 Research Professor ; on retirement in 1960 he was appointed Emeritus Professor.

He published a total of 86 papers ; some of them, notably those on ionised gases and the ionosphere remain as standard authoritative works. Three papers were published in the Society's " Journal and Proceedings " for one of which entitled " Net Electric Charges on Stars, Galaxies and 'neutral' elementary particles ", he was awarded the Archibald D. Ollé Prize for 1961. Not long before his death, Professor Bailey learned that the predictions on the Interplanetary Magnetic Field made by him in 1960 (and relevant to the paper for which he received the Ollé Award) had been confirmed by five U.S. Space Satellites. This news was received on the occasion of his visit to Rome for the Galileo Celebrations where he read three papers.

In 1935, the Society awarded Professor Bailey the Walter Burfitt Prize. Other awards included the T. K. Sidey Medal and Prize by the Royal Society of New Zealand, by his appointment to Visiting Research Professorships in the U.S.A., and by his election to the chairmanship of a committee of the International Union of Scientific Radio.

He was elected to membership of the Society in 1924.

Professor Bailey is remembered by many of his colleagues for his outstanding achievements and lively personality.

Professor Bailey is survived by his wife, two sons and two daughters.

Frank Andrew Coombs, who died on 21st October, 1964, was born in 1877 at Dunedin, N.Z.

The late Mr. Coombs studied analytical and practical chemistry under Professor Black at the Otago University in 1898–1900. In 1908 he came to Sydney. He applied for the position of Instructor in tanning and currying and was successful in being appointed ; a position he held for 35 years. Mr. Coombs was the first to teach tanning, etc., in Australia or New Zealand, and the first man to tan a shark skin. Whilst teaching at Sydney Technical College, he studied at Sydney University, combining with his studies research in Australian barks, wattles, mangroves, eucalyptus, etc., in connection with tanning agents for the leather industry.

He was a Fellow of the Chemical Society, and a foundation member of the Australian Chemical Institute.

He introduced science into the Australian leather industry and formed the Australian section of the I.S.L.T.C., being its first President. For his services to this he was made an Honorary Life Member in 1948.

His work was known in Britain, U.S.A., France, Germany.

During the last war, he was on loan to the Federal Government to inspect the leather for Army boots, etc.

Several of his papers on Leather, Barks, etc., have been read before the Royal Society of New South Wales and other societies.

Mr. Coombs was elected to membership of the Society in 1913 and had had five papers published in the " Journal and Proceedings " of the Royal Society of New South Wales.

He is survived by his wife and three sons and one daughter.

John Ralph Bardsley, a member of the Society since 1919, died on 26th February, 1965. Mr Bardsley was born at North Adelaide, South Australia, on 6th November, 1892. He was educated at the Public School, and then at Pulteney Street Church of England School. He came to Sydney with his parents and older brother George in 1902 when they started a family business. He attended Fort Street Boys' High School 1903–08, and continued his studies at Sydney Technical College in Inorganic and Organic Chemistry, and other minor subjects, to assist him in his business as a hat manufacturer.

During most of his business life, and until his death, he was a Director, and in charge of the laboratory and processing work at John Bardsley and Sons, Pty. Ltd.

Mr. Bardsley is survived by his wife, four sons and two daughters.

Kenneth Phillip Forman, who died suddenly on 23rd October, 1964, while on a business trip to Melbourne, was born at Brisbane on 16th June, 1902. For the past seventeen years he had been the Australian Field Representative of the McGraw-Hill Publishing Co., New York, and was in charge of the field salesmen in the Far East.

At the beginning of World War II, Mr. Forman was appointed to the Aircraft Production Commission, later the Department of Aircraft Production, and eventually took up duties in Washington, D.C., with Australian War Supplies Procurement. Prior to the war he was associated with EMAIL and the Westinghouse organization.

He was educated at Brisbane and in 1917 was dux of the Church of England Grammar School.

Mr. Forman had been a member of the Society since 1932.

He is survived by his wife and one son and one daughter.

Anthony Gerard Fynn, the son of J. Fynn, Kilmore, Victoria, was born on 11th September, 1899, at Yea, Victoria. He was educated at Xavier College, Kew, and at University College, Dublin. He entered the Society of Jesus, 1st February, 1918, and was ordained Priest on 31st July, 1933.

During 1920–23 he directed the seismological station, Dublin; studied Philosophy at Ignatius College, Valkenburg, Holland, 1923–26; taught Mathematics at Xavier College, 1926–30; studied Theology, Dublin and Austria, 1930–35; and was Professor of Philosophy and General Science, Loyola College, Watsonia, Victoria and at Canisius College, Pymble, N.S.W.

He joined Riverview Observatory in 1958 and was appointed Director in 1959 which position he held until his death on 2nd February, 1965.

Father Fynn prepared the vault and arranged with the U.S. Coast and Geodetic Survey that they install a set of standard instruments at Riverview, and make it a station of the world-wide standard network. The instruments commenced recording in December, 1962.

Father Fynn had been a member of this Society since 1959. He was a member of the Council for the years 1960–63.

Jack Murielle Somerville, Professor of Physics in the University of New England, died suddenly on October 15th, 1964. Though his silver hair made him look older, he was only 51.

He started his career as a mathematician and, after studying at the University of Sydney, he won a Barker Scholarship to Emmanuel College in the University of Cambridge, the traditional home of British Mathematics. When he returned to Australia in 1937, however, he began to renew his interest in physics and in 1938 he was appointed as one of the foundation members of the staff of the New England University College where he was in charge of all teaching in both mathematics and physics. Thus began his long association with the present University of New England, an association interrupted for only four years during the war when he returned to Sydney University as Assistant Director of Radiophysics Training in a wartime school to train operators and technicians in the then new science of radar.

The New England University College began as an institution more devoted to teaching than to research, but on his return to Armidale in 1945 Professor Somerville began the nucleus of a research group which today has some 20 permanent staff members and 15 post graduate research students.

When the University of New England was created in 1954, he was appointed as its foundation Professor of Physics and continued as Head of the Department of Physics until his death. Under his leadership research groups were built up in ionospheric physics, solid state physics and in his own particular field of interest—the physics of ionized gases, or plasmas, and the electric glows, arcs and other discharges which may occur in them.

In this field he was an internationally known expert. He published some 20 papers in scientific journals as well as a monograph on the Electric Arc. He had been invited to write a new book on Spark Channels for an international series on discharge physics and at the time of his death this work was about half written.

The many students who have passed through the University of New England Physics Department in the last 25 years will remember Professor Somerville as an inspiring teacher and one who delighted in simple demonstrations, particularly of electrical phenomena. He avoided mathematical complexity wherever possible and liked to discuss difficult problems from first principles.

To those who became research students and to his colleagues on the staff he was a very dear friend who could always be looked to for advice and help in any complicated situation and for a well-chosen story to lighten the occasion. He was much sought after on committees both within and outside the University and was a member of the Committee at present drafting the new Science syllabus for secondary schools in New South Wales, a member of the Council of the Australian Institute of Nuclear Science and Engineering and a member for many years of the Council of the University of New England.

Professor Somerville will be sadly missed by his many friends and colleagues. His permanent memorial will be the Department of Physics which he founded in New England University.

Professor Somerville was elected to membership of the Society in 1959.

Citations

James Cook Medal

Max Rudolf Lemberg took his Ph.D. in Breslau in 1921, and of the subsequent 44 years, 30 have been spent in Australia. After some seven years of organic chemical research his attention turned in 1928 to the chromoproteins of red algae; he succeeded for the first time in isolating the prosthetic groups of phyocyanin and phycoerythrin, and established their structures as the bile pigments mesobiliviolin and mesobilierythrin respectively. Through these studies his interests were turned definitely and permanently to biochemistry, and to the pyrrole pigments in particular. Over the period 1933–1949 he made important contributions to knowledge of the chemistry and structure of many bile pigments, and to the mode of their formation by degradation of haemoproteins. During this period he built up a knowledge of the pyrrole pigments and haemoproteins which enabled him to publish with J. W. Legge in 1949 "Haematin Compounds and Bile Pigments", which because of its extraordinary scope, in depth as well as in breadth, will long be the definitive text in the field. During the studies of the degradation of haemoglobin to bile pigments, compounds had been observed with spectroscopic and apparent chemical relationships to haem *a*, the prosthetic group of cytochrome oxidase. The structures of some of these compounds (cryptoporphyrin PI and cryptoporphyrin i) have recently been established in his own laboratory; they are derivatives of protoporphyrin, and the relationship of their structures to porphyrin *a* is not as close as was suspected. Nevertheless these observations perhaps stimulated Lemberg's interest in haem *a* and the cytochromes *a*, which have furnished the main theme of his studies from about 1949 to the present. At the Haematin Enzymes Symposium in Canberra, of which he was President, the culmination of ten years study of haem *a* came with his announcement of most of the details of its structure. Since that time his attention has turned more and more from the prosthetic group to the whole cytochrome. He described in 1962 the preparation of compounds resembling the natural haemoproteins *a*, formed by combination of haem *a* with a variety of pure proteins and lipids, and showed the importance of lipids in the natural cytochrome complex. More recently, his studies of native cytochrome oxidase are clarifying the nature and mode of action of this supremely important enzyme.

Lemberg's scientific papers at present number well over 100 and in addition he has published many reviews and general articles. Lemberg's work and writing are characterized by great scholarship and depth. His thinking is supported by knowledge and understanding which range over the whole field of current biochemical research, and this has frequently allowed him to advance fruitful hypotheses well ahead of experimental confirmation. This was exemplified by his penetrating and imaginative postulate (1949) that the biosynthetic pathway to haems lay through the condensation with glycine of an intermediate arising from the tricarboxylic acid cycle, leading to a key monopyrrolic precursor with acetic acid and propionic acid side-chains. It was not until years later that this was shown indeed to be the case.

Dr. Lemberg has been a member of the Society since 1936; has served on Council and was President in 1955.

In 1954 Dr. Lemberg delivered the Liversidge Research Lecture entitled "Chemical Structure and Biological Function of the pyrrole pigments and enzymes".

Clarke Medal

Dr. Mackerras (*nee* Bancroft) graduated M.Sc. at the University of Queensland and M.B. at Sydney. She held a Walter and Eliza Hall Fellowship and practised medicine. Dr. Mackerras was a Research Officer, C.S.I.R. Department of Entomology, Canberra, from 1930 to 1947. During World War II, she served five years with the rank of Major, being in charge of the entomological side of anti-malarial research. From 1948 to 1961, she was Parasitologist at the Queensland Institute of Medical Research, and is still a part-time Principal Research Officer in the C.S.I.R.O.'s Department of Entomology. Her distinguished work on entomology and parasitology from the medical standpoint is attested by a bibliography of some 70 papers by herself or in joint authorship with T. H. Johnston, with her husband Dr. I. M. Mackerras, and other colleagues.

The Society's Medal

The Society's Medal for 1964 is awarded to Mr. F. D. McCarthy for distinguished contributions to anthropology and service to the Society.

Mr. McCarthy's contributions to the fields of archaeology and cultural anthropology have been impressively numerous and varied but also of the highest standard. His scientific reputation stands high in overseas archaeological and anthropological circles, as well as here in Australia and we feel that this award is a fitting tribute to a scholar who has done much to advance these disciplines.

Mr. McCarthy has been a member of the Society since 1949 ; has served on the Council and was elected President in 1956.

Recently, Mr. McCarthy was appointed Principal of the Australian Institute of Aboriginal Studies in Canberra.

Edgeworth David Medal

The morphology and pharmacology of the autonomic effect or systems have been intensively studied since the last century but it is only within the last decade or so that striking advances have been made in our understanding of the physiology of smooth muscle. This has come about largely because of the application of modern electrophysiological techniques and particularly the use of the intracellular electrode. The use of the intracellular electrode was pioneered by Dr. Bülbring and her colleagues at Oxford in 1954 using the smooth muscle fibre in the rabbit's sphincter pupillae and immediately applied by her to the taenia coli preparation in the guinea pig. It was very soon after this (1956) that Dr. Mollie Holman went to the Department of Pharmacology at Oxford to work under Dr. Bülbring. Here she mastered the techniques involved in the taenia coli preparation and published two important papers on the effects of changes in the ionic environment on the electrical and mechanical activity of smooth muscle. With these papers she established herself as one of the pioneers in the field of smooth muscle physiology and she has continued to play a leading part in the various developments that have taken place since that time.

While in Oxford she first became associated with Dr. Burnstock in a partnership which was subsequently to be resumed when she returned to Melbourne.

In addition to their physiological studies Burnstock and Holman have also made important contributions to the pharmacology of smooth muscle. Recently, as associates of Dr. Neil Nerrillees, they have published a correlation of the fine structure and physiology of the innervation of smooth muscle in the guinea pig vas deferens using the electron microscope.

The importance of the contribution that Dr. Holman has made to the physiology of smooth muscle, and the international reputation she has established for herself has been indicated by the fact that she and her colleague Dr. G. Burnstock were invited to contribute the chapter "Smooth muscle: autonomic nerve transmission" in the Annual Review of Physiology, 1963.

Royal Society of New South Wales

OFFICERS FOR 1965-1966

NOTICE

The Royal Society of New South Wales originated in 1921 as the " Philosophical Society of Australasia " ; after an interval of inactivity it was resuscitated in 1850 under the name of the " Australian Philosophical Society ", by which title it was known until 1856, when the name was changed to the " Philosophical Society of New South Wales ". In 1866, by the sanction of Her Most Gracious Majesty Queen Victoria, the Society assumed its present title, and was incorporated by Act of Parliament of New South Wales in 1881.

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JOURNAL AND PROCEEDINGS

OF THE

ROYAL SOCIETY OF NEW SOUTH WALES

VOLUME 98 1965 PART 4

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NOTICE TO AUTHORS

General. Manuscripts should be addressed to the Honorary Secretaries, Royal Society of New South Wales, 157 Gloucester Street, Sydney. Two copies of each manuscript are required: the original typescript and a carbon copy; together with two additional copies of the abstract typed on separate sheets.

Papers should be prepared according to the general style adopted in this Journal. They should be as concise as possible, consistent with adequate presentation. Particular attention should be given to clarity of expression and good prose style.

The typescript should be double-spaced, preferably on quarto paper, with generous side margins. Headings should be typed without underlining; if a paper is long, the headings should also be given in a table of contents typed on a separate sheet, for the guidance of the Editor.

The approximate positions of Figures, Plates and Tables should be indicated in the text between parallel ruled lines. Captions of Figures and Plates should be typed on a separate sheet.

The author's institutional or residential address should be given in the title of the paper, the relevant author's initials being attached in brackets to the appropriate address in cases of papers written jointly.

Abstract. An *informative* abstract should be provided at the commencement of each paper for the guidance of readers and for use in abstracting journals.

Tables. Tabular matter should be type-written on separate sheets, arranged for the most economical presentation on the printed page. Column lines should *not* be ruled in. Units of measurement should always be indicated in the headings of the columns or rows to which they apply. Tables incorporating both text and line diagrams (including dotted lines and shading) should be submitted in a form suitable for direct reproduction by photographic line blocks.

References. References are to be cited in the text by giving the author's name and the year of publication, e.g.: Vick (1934); at the end of the paper they should be arranged alphabetically giving the author's name and initials, the year of publication, the title of the paper (if desired), the abbreviated title of the journal, volume number and pages, thus:

VICK, C. G., 1934. *Astr. Nach.*, **253**, 277.

The abbreviated form of the title of this journal is: *J. Proc. Roy. Soc. N.S.W.*

Captions of Figures and Plates should be typed in numerical order on a separate sheet.

Line Diagrams. Line diagrams, fully lettered, should be made with dense black ink on either white bristol board, blue linen or pale-blue ruled graph paper. Tracing paper is unsatisfactory because it is subject to attack by silverfish and also changes its shape in sympathy with the atmospheric humidity. The thickness of lines and the size of letters and numbers should be such as to permit photographic reduction without loss of detail.

Dye-line or photographic copies of each diagram should be sent so that the originals need not be sent to referees, thus eliminating possible damage to the diagrams while in the mail.

Photographs. Photographs should be included only where essential, should be glossy, preferably mounted on white card, and should show as much *contrast* as possible, since contrast is lost in reproduction of half-tone blocks. Particular attention should be paid to contrast in photographs of distant scenery and of geological subjects. When several photographs are to be combined in one Plate, the photographs should be mounted on a sheet of white bristol board in the arrangement desired for final reproduction.

Geological Papers. Except in special circumstances, authors submitting manuscripts in which new stratigraphical nomenclature is proposed must also submit the letter of approval of or comment on the new names from the appropriate nomenclature sub-committee of the Geological Society of Australia.

Reprints. Authors who are members of the Society receive 50 copies of each paper free. Additional copies may be purchased provided they are ordered by the author when returning galley-proofs.

THE AUTHORS OF PAPERS ARE ALONE RESPONSIBLE FOR THE STATEMENTS MADE AND THE OPINIONS EXPRESSED THEREIN.

Journal and Proceedings, Royal Society of New South Wales, Vol. 98, pp. 197–202, 1966

Current Trends in Solid State Science

The Pollock Memorial Lecture

DR. FREDERICK SEITZ

President, National Academy of Sciences, U.S.A.

It is my privilege to spend this hour honoring your great physicist Professor V. A. Pollock by attempting to give you a broad review of the field of solid state physics—a field which has not only been remarkably coherent during several centuries of the development of western science, but has also been highly productive both as a source of the kind of enlightenment for which we value science so much and as a contributor to technology.

In examining the evolution of any field of science, we may note that the process of development often resembles somewhat the evolution of a mining operation. In the early stages of mining for a new and relatively little used material, one focuses on very rich deposits which give the most concentrated products that can be recovered and used most easily or directly. In fact only such deposits may have significant value in the early stages of the mining operation. Later, as the material being sought becomes more useful, and as the technology for developing it expands, one may find that leaner, lower-grade deposits are exceedingly important. In fact, the major wealth associated with exploitation of the mineral may eventually be associated with the relatively leaner deposits, as is true, for example, for the highly mechanized production of gold in the South African mines of the Rand Area.

Something quite analogous to this pattern is visible in the history of the opening of major areas of solid state science, as the field as a whole has gone through successive cycles of advance. In any one stage of development, attention is focused initially on major principles. Many of the details stemming from the principles are, in the main, of intellectual interest only to those few who have a very special appetite for them. Ultimately, however, as the knowledge of a given area becomes absorbed into useful technology, what were initially regarded as secondary facets of the subject may come to have practical interest. Thus, as time goes on, the apparently leaner aspects of the subject can become of very great practical importance.

By way of introduction, let me remind you that the crystalline solids formed by the elements and their compounds can be classified into four broad categories, namely, the salts, metals and alloys, valence crystals, and organic or molecular solids. The alkali halides and alkaline earth oxides are typical salts. About 70 per cent of the pure elements are metallic, that is, are good electronic and thermal conductors and tend to alloy readily with one another. Carbon, silicon, germanium, gray tin, and silicon carbide are typical valence crystals. The organic, or molecular solids, comprise the most diversified group, ranging from simple systems like solid carbon dioxide to quite complex crystalline polymers, such as polyethylene, or the natural organic polymers which play such an important role in biological systems.

The four categories are not all pure, for many materials have properties that lie intermediate between these of two or more types. For example, there are many alloys which are very close to being electrical insulators and resemble the salts or valence crystals in composition and atomic arrangement.

A number of salts and valence crystals, which are good insulators at low temperatures, become electronic conductors at elevated temperatures because bound electrons become free as a result of thermal excitation. These solids are, of course, the semi-conductors; the electrons which become free may be either the normal bonding electrons in the valence shelves or may be associated with distinctive impurities or foreign atoms which are added.

* *Delivered at the University of Sydney, Sydney, Australia, August* 1-26, 1965.

In a similar way, the various areas of development of solid state science may be broken into five major fields which interlock closely with one another, although the " mining " of each of the fields generally started at different times on the historical scale. The five fields are as follows :

1. Macroscopic Properties
2. Lattice Structure
3. Electronic Structure.
4. Imperfections
5. Surface Properties.

The macroscopic properties are concerned with those characteristics of solids that can be measured on specimens having substantial size, that is having linear dimensions of the order of millimeters, or larger. Initially, the studies were concerned with the geometrical relationships of natural-formed crystals, usually mineralogical specimens, and led to the formulation of laws such as those governing the constancy of angles between neighbouring faces in a given crystalline habit form of a specific compound. Eventually the study was extended to the measurement of mechanical, electrical, magnetic, and thermal properties of the specimens in various crystalline directions and various temperatures. The subject is sometimes referred to in terms of the " tensor " properties of crystals. Systematic studies of natural specimens of this type were responsible for the discovery of piezoelectricity and pyroelectricity. Although such effects were initially of purely scientific interest, they eventually led to very important applications of crystalline specimens, such as in polarizing prisms, piezo-oscillators, and sonic transducers.

A desire to broaden the range of available crystals, starting in the early part of this century, inspired the evolution of a number of techniques for growing large single crystals of interesting materials. Such crystals have turned out to have great technical value in their own right in numerous applications such as in relation to jewelled bearings, magnetic materials, transistors, optical lenses and prisms for the ultraviolet and infrared, and ultimately in the field of laser research. Among the techniques used for growing crystals are those of evaporation of aqueous solutions, stress annealing, the Kyropoulos method (drawing from the melt), the Bridgman method based on use of the thermal-gradient baffle, the boule or arc-melting method, the zone method and hydrothermal techniques.

It is particularly interesting historically to note that natural radio-activity was discovered by Becquerel incidental to the study of the physical properties of many crystalline materials.

Similarly, superconductivity was discovered by Kammerlingh Onnes in 1911 as the result of a systematic investigation of the conductivity of metal at low temperatures.

Although we think of crystalline masers and lasers, which generate coherent electromagnetic radiation in the high radio or optical range of frequencies, in quite modern terms because they were developed in the recent past as a result of the study of quantum phenomena in gases and molecular beams, the action of these solid state systems actually can be regarded to lie in the macroscopic domain since the underlying phenomena depend on the co-operative interplay of the entire assembly of radiating atoms with the radiation field. Thus, even though the study of the macroscopic properties of crystals is old, the field continually yields new dividends as more and more techniques in which the macroscopic properties of crystals can play a role are developed.

Lattice Properties. At the time of Dalton, early in the last century, when the atomic hypothesis was gaining ground, the conjecture was offered that the regular form of natural crystals implies an orderly stacking of the constituent atoms into lattice-like array. In brief, it was postulated that crystals contain a basic geometric unit of atoms or molecules, the lattice cell, which is repeated over and over in a periodic way in three directions. This relatively speculative concept evolved steadily during the last century, until, near 1900, imaginative scientists began to propose detailed structures for the simpler crystalline compounds. In the meantime, the geometrical theory of three dimensional lattice arrays had been worked out in much detail by mathematicians, starting with Bravais in 1830, and extending on toward the end of the century.

The study of the lattice properties of crystals entered into a completely new era when in 1913 it was discovered that crystals diffract X-rays in a manner determined by the lattice arrangement. This discovery was augmented by the discovery of electron diffraction in 1929 and neutron diffraction in 1944. At first, diffraction techniques were used to determine the properties of the simpler inorganic crystals. Eventually, however, the methods were employed both in the investigation of more complex inorganic organic structures such as the silicates

and of relatively imperfect crystals. The highest points in the development of diffraction techniques achieved thus far occurred in the last ten years in connection with organic crystals, for example, in the discovery that the long molecules in crystals of polymers are folded, and in the discovery that the molecules of Deoxyribose Nucleic Acid (DNA), which enter in such a crucial way in gene material, are double spirals, each member of the spiral being closely correlated along the length according to precise rules of combination. One can only feel a sense of inspired awe when contemplating the fact that the early speculations on the lattice properties of crystals nearly 150 years ago eventually led to the evolution of techniques for determining the pattern of arrays in the genetic material responsible for the replication of biological species.

Along somewhat different lines, it may be noted that the dynamic properties of the crystal lattice have made it possible to use crystalline materials to obtain valuable specialized information regarding nuclear energy levels in a number of elements. When a stationary, isolated nucleus emits or absorbs a gamma ray, the net momentum transferred to the nucleus is sufficiently large that the absorbed and emitted quanta have energies significantly different from the spacing of the nuclear levels involved in the transition. On the other hand, when the nucleus is in an atom bound into a crystal, it is possible, under proper circumstances, for the entire crystal specimen to absorb the momentum so that the energy of the absorbed or admitted quanta is very nearly the same as the nuclear level spacing. This effect, discovered by Mössbauer, makes it possible to use crystalline emitters and absorbers to obtain much detailed knowledge concerning nuclear energy levels.

Electronic Properties. In the 1880's, early in his long and productive career, the Dutch physicist H. A. Lorentz postulated that insulating materials contain bound charges which are held in position by harmonic forces, much like weights which are attached to a fixed point by an ideal spring. The existence of such changes had been surmised earlier from the laws of electrochemical equivalence but they had not been employed previously in considering the dynamical properties of atomic structure. In terms of this picture, Lorentz was able to explain the variation of the optical dielectric constant of crystals near regions where the crystals absorb light. In this way the concept of the electron entered solid state science. Much more tangible evidence for the electron was developed a decade later when investigators began studying the fragments of atoms produced in gaseous discharges. Then, at the turn of the century, Drude proposed that metals contain a gas of free electrons which are responsible for their high electrical conductivity and started a very fruitful period of study of metals.

The understanding of the electronic properties of solids remained in a very primitive state until quantum mechanics was developed about 1925. Following that, it became possible to discuss the detailed behaviour of the valence electron in many crystalline materials. Investigation of the wave equation showed that the energy levels of electrons could be grouped into bands whose relationships gave, in turn, a simple and direct explanation, not only of the characteristic differences between metals and insulators, but of the ways in which transitions between the two types of materials occur. By 1940 one had an excellent semi-quantitative understanding of the behaviour of the valence electrons in many typical simple solids.

The development of electronic computers during and after the war made it possible to expand the detailed investigation of the electronic states in solids on a relatively enormous scale. Today, because of such computers, it is feasible to hope to obtain quite detailed knowledge of the levels or bands in many monotomic or diatomic solids. Studies of this kind have been accelerated substantially by the widespread practical interest in the detailed behavior of conduction electrons in the useful semiconductors such as silicon and germanium, and the compounds of elements in the third and fifth columns of the periodic chart.

One of the greatest triumphs of the electron theory of solids has been the achievement, within the last decade, of a high degree of understanding of the phenomenon of superconductivity, particularly as a result of the work of Bardeen, Cooper, and Schrieffer. These investigations have shown that in cases in which the free valence electrons in the metal are disturbed sufficiently by the vibrations of the crystal lattice, or, to use the accepted language, interact sufficiently strongly with them, this interaction may have a significant influence on the behaviour of the motion of the electrons relative to one another. At relatively low temperatures, within a few degrees of the absolute zero, this effective electron interaction, originating in the inter-

action of the electrons with the lattice vibrations, may cause the electron gas to freeze into a mode of motion in which pairs of electrons which move in opposite directions with equal momentum are closely correlated even though they may be separated in space by many atomic distances. This correlation not only influences the way in which the electron gas conducts an electric current, inducing typical superconductive characteristics, but also determines the behaviour of the electrons in a magnetic field. In effect, the ideal homogeneous specimen behaves like a perfect diamagnetic for which the permeability vanishes (Meissner effect), that is it rejects lines of magnetic force.

The development of a consistent quantum mechanical theory of superconductivity has given an enormous impetus to the study of the entire field of superconductivity in recent years. Out of this work has emerged not only the discovery and refinement of many new superconducting compounds but also the discovery that the magnetic field associated with a supercurrent is quantized, that is, its intensity is restricted to discrete values which depend upon the geometry of the superconducting system. On the technical side, the refined studies have made it possible to construct permanent superconducting magnets which can produce magnetic fields in the vicinity of 100,000 Oersted. The superconductors used in such magnets, usually termed hard superconductors, have the property that they are not physically homogeneous and are able to retain lines of magnetic force that are trapped at imperfections in a way not yet thoroughly understood. The trapped lines of magnetic force reside near the centre of vortices of supercurrent.

Still further, there has been extensive study of the way in which conduction electrons flow from one superconducting metal to another as the spacing between the two is varied from zero to many atomic distances (tunneling effects). Such developments promise to yield an enormous amount of additional information concerning superconductivity, some of which may have very useful consequences.

The methods of mathematical analysis used in the theory of superconductivity are based on a combination of the methods of field theory, first developed in connection with high energy particle physics, and the methods of many-body theory, developed to handle problems involving the co-operative action of many particles. The success of this approach to the problem of superconductivity has opened a large doorway to the theoretical investigation of many other problems of solid state science.

Imperfections in Crystals. The concept of the ideally perfect crystal in which the lattice array is entirely unblemished is an abstraction normally realized only on a quite microscopic scale within a larger specimen. All real crystals contain varying degrees of imperfection. It was recognized very early in the history of the development of crystal science that imperfections are present in typical specimens. Indeed many irregularities could be seen with the naked eye, under the microscope, or discerned indirectly by chemical analysis. It was also recognized very early that imperfections must play a significant role in affecting the physical and chemical properties of specimens since the properties could be made to vary by altering the imperfections. On the technological side, the control of accidental or intentional additions or structural features has always been an important part of the practical lore in fields such as ceramics and metallurgy. Practical studies showed, in fact, that imperfections may be relatively inert in some cases; whereas they may have profound effects upon the properties in others, such as in the case of additions of carbon in iron.

To give another example, the entire field of crystalline luminescence underwent a vast development in the first quarter of the present century in the hands of the chemists, who studied the influence of various foreign additions on the luminescent properties of salts when irradiated with ultraviolet light, X-rays, or ionizing particles. Along similar lines, it was noted that the semi-conducting behaviour of many substances such as selenium, tellurium, and lead sulphide is critically dependent upon the presence of foreign atoms. Still further, it was found that the ductility of relatively plastic crystals such as metals and salts could be influenced enormously by changing the state of perfection of the specimens.

Following 1925 there was a strenuous attempt to catalog the possible imperfections that could occur in crystals and to sort out the influence which they have upon the physical and chemical behaviour of such solids. This work actually did not come to complete fruition until after World War II, when the subject received international attention on the massive scale which the postwar support of science made possible. It was then realized that the types of imperfections which can occur in solids are rather small in number. The great diversity of effects arising from the imperfections is to a

considerable degree a result of the complex interactions between imperfections which can occur.

Basically there are three families of imperfections, namely: point imperfections, such as foreign atoms present in the lattice either substitutionally or interstitially, or vacant lattice sites produced by removing atoms from the lattice (vacancies); electronic imperfections such as additional free electrons in an otherwise insulating matrix, generated, for example, by adding an atom with a loosely bound electron to the lattice; line imperfections, generally termed dislocations, such as may be produced by permitting the atoms on opposite sides of a planar area within the crystal bounded by a line or curve to slide past one another by one cellular distance in such a way as to cause a pattern of disregistry along the bounding line.

Each of these three basic types of imperfections can not only interact with imperfections of the same type but can also interact in various ways with the other two types to produce a wide variety of effects. It has been demonstrated, for example, that the plastic properties of simple crystals are closely associated with the ability of the linear dislocations described above to move through the lattice when it is placed under shearing stress. The interaction of dislocations with one another and with foreign atoms provides an explanation of the sensitivity of such plastic flow to cold work (extensive deformation) and to foreign atoms.

Although a large part of the research carried out in the field of solid state science between 1945 and 1960 was devoted to the clarification of the influence of imperfections on the properties of solids, the field still provides an enormously fruitful area for further research, particularly as new techniques for investigation are developed. Moreover, there are a number of facts which are not at all well understood. It is known, for example, that special crystals, such as zinc and cadmium sulphide, undergo a special type luminescence (electroluminescence) when placed in an oscillatory electric field. Investigations show that the emitted radiation probably originates near imperfections; nevertheless the nature of the interaction between the applied field, the luminescent centers, and the imperfections is not at all clearly understood at the present time.

Surface Properties. Every real crystal is bounded by a surface. Such surfaces have been studied systematically over many decades in an attempt to evolve systematic knowledge of the surface properties. The initiating investigations, in areas which still continue to be productive, were carried out by chemists concerned with such phenomena as surface adsorption and surface catalysis. In close relation to this, chemists and mineralogists studied the nature of crystalline layers formed by depositing one compound on the surface of another (e.g., epitaxy).

In a similar way, metallurgists have studied the influence of intercrystalline boundaries in polycrystalline materials (grain boundary effects).

Since 1945, several new types of studies have given added impetus to the investigation of surfaces. For example, Professor Mueller showed that one could obtain very interesting information about the atomic arrangements of the base material and deposited materials in the outer layers of point electrodes which were placed in electric fields sufficiently strong to induce field emission of electrons. I have been pleased to see important extensions of this work in the CSIRO laboratories in Melbourne. While this work has been rather specialized in the sense that it is focused on the use of a few metals, it has given a wealth of information concerning the influence of the underlying crystalline arrangement on foreign layers on the surface of such metals.

Soon after the war, John Bardeen pointed out that the conductivity of thin semi-conducting layers or filaments could be greatly influenced by the nature and condition of the surface. He emphasized that surface atoms had their own characteristic electronic energy levels, and that these levels could influence the number of conduction electrons present in a region near the surface. Since the pattern of surface atoms can be influenced in turn by adsorption, it follows that under proper circumstances there can be a correlation between volume conduction and surface conditions.

Still more recently, a number of investigators have developed techniques for studying diffraction of electrons of very low energy by crystalline surfaces. Such electrons, having energies near 100 electron volts, do not penetrate the specimen by more than a few atomic distances, so that the diffraction pattern is characteristic of the outer layers. Many individuals place high hopes on the promise of this new method of study for obtaining profound information on a wide diversity of surfaces. This approach to the study of surfaces

has been featured at the recent Melbourne Conference on Diffraction.

In spite of the progress that has been made over the decades in the study of crystalline surfaces, one must admit that the field is unfolding relatively slowly. Although there presumably will come a day when there is as much understanding of the surface properties of solids as we have at present of the volume properties, it does appear that a whole new regime of development will be needed to achieve that goal.

My own involvement in the science of solids now goes back somewhat over 30 years beginning with the early development of the theory of electron bands in solids. It is interesting to contemplate that a very major fraction of the quantitative and qualitative knowledge of solids which we possess at present has been developed over that span, in spite of the fact that the field is, in itself, several hundred years old. If I attempt to analyze my own experiences over this period, I find that one of the most remarkable features, apart from the advance in understanding, has been the fact that the interest in detailed facts has grown so much. In the 1930's, it seemed quite reasonable for one person to be familiar with practically all of the available literature concerning solids and much of the implication of the work. Now a typical good investigator may devote a number of years to one highly specialized facet of a given family of compounds and have relatively little knowledge of a topic which, although fairly closely related to his interest, is not immediately tied to it. Coupled with this increasing concern about detail has been a vast growth in the number of highly competent scientists working in the field and in the range of knowledge which has direct applied interest. From the detailed study of properties, there has been spawned families of devices including a large array of transistors, a spectrum of magnetic materials for transformers and recording devices, luminescent screens of varied use, superconducting magnets and crystalline lasers.

One might reasonably ask whether the field of solid state science is in its infancy or its old age. It clearly is not in its infancy for we now have far too much accumulated knowledge of the properties of a wide family of solids to assume that the field is not mature. Moreover, there are very few outstanding mysteries extant at present, as was true when I entered the field some 30 years ago. On the other hand, I cannot help but feel that there is still a vast amount of valuable " ore " left in the study of solids. The realization of that ore in the future will depend upon the careful and systematic study of detailed properties of many compounds, using all the battery of physical and chemical techniques which are now available and can be devised in the future. In a sense, the field can be looked upon henceforth as somewhat in the nature of a very sophisticated branch of chemistry, which will persistently yield significant new discoveries if a host of competent investigators continue to pursue a wide variety of investigations.

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On Lepidopteris madagascariensis Carpentier (Peltaspermaceae)

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ABSTRACT—The pteriodosperm leaf *Lepidopteris madagascariensis* Carpentier, hitherto very little known, is redescribed from material coming mainly from the Gosford Formation of the Narrabeen Group (Lower Triassic) of New South Wales. The distinction between *L. madagascariensis* and *L. stormbergensis* (Seward) Townrow is discussed, and some specimens reclassified. Evolution in *Lepidopteris* is considered and its stratigraphical range discussed.

Introduction

The leaf *Lepidopteris* Schimper belongs to the small pteridosperm family, the Peltaspermaceae Thomas (1933), recently discussed and extended by Townrow (1960). In that discussion, two leaf species could be little utilised, they were too ill known, *L. stuttgardiensis* (Jaeg.) Schimper, the Type, from the German Upper Triassic, and *L. madagascariensis* Carpentier, from the Triassic of Madagascar. *L. madagascariensis* has been somewhat eclipsed by the commoner *L. stormbergensis* (Seward) Townrow, but proves to be a useful and well characterised species. It is, in part, Lower Triassic in age, and serves to tie in the Permian *L. martinsii* (Kurtze) Townrow more closely with the rest of the Family. It may also prove to be useful stratigraphically. Nothing is known of the reproductive structures of *L. madagascariensis*.

Descriptions

FAMILY PELTASPERMACEAE Thomas (Pteridosperms)

GENUS *LEPIDOPTERIS* Schimper

Lepidopteris madagascariensis Carpentier

Pl. 1 Figs. 1–4

1907 *Alethopteris* nov. sp. Dun p. 155. Mention in bore log. Material here re-examined.

? 1908 *Thinnfeldia sphenopteroides* Seward, pp. 94–95; pl. 4, fig. 2 only; Uppermost Beaufort, S. Africa., pl. 5, fig. 2 is distinct.

1927 *Lepidopteris stuttgardiensis* du Toit, non Jaeger, pp. 400–401, pl. 28, from the uppermost Beaufort.

? 1927 *Callipteridium africanum* du Toit, p. 404, pl. 27. From the uppermost Beaufort; unusually large leaf. Pl. 26, figs. 2, 3 are distinct.

1935 *Lepidopteris madagascariensis* Carpentier, p. 14, pl. 3, figs. 3–5, pl. 5, figs. 4 and ? 6, from the Sakamena Group, Madagascar.

1936 *Lepidopteris madagascariensis* Carpentier: Carpentier, p. 9, pl. 5, fig. 4 and ? 5–7, from the Sakamena Group, Madagascar.

? 1956 *Lepidopteris stormbergensis*. Townrow, non Seward, p. 23, text figs. 2A, H; 3B; 6 A, B. Brookvale, N.S.W., Hawkesbury Sandstone.

1960 *Lepidopteris madagascariensis* Carpentier: Townrow, p. 339. Note only. Holotype: Carpentier, 1935, pl. 3, figs. 3 and 4.
Locus typicus: Amboriky, Madagascar; Sakamena Group, Lower Triassic.

Diagnosis emended. Leaf bipinnate up to 28 cms. long, with about 15 pinnae, emerging at 90° or more, at base of leaf, angle diminishing to about 60° at apex. Pinnae 0·75–1·5 cms. apart, margins usually not touching. Pinnules from 2·5 mm. × 1·25 mm. to 6 mm. × 3 mm.; normally not overlapping one another, often slightly separated, usually entire, or with slightly lobed margins, obtuse apex, and margins usually parallel over nearly all the length of the pinnule. Venation extremely obscure, consisting of a midrib and laterals arising at an angle of about 45° to the midrib every 0·75 mm. approximately. Zwischerfiedern arising on or near the lower (abaxial) rachis surface, two or three between pinnae, somewhat rhomboidal, apex very obtuse, 1–3 mm. long and same wide.

Substance of leaf thick ; margins not scarious nor thickened.

Cuticle thick, 3μ and more (measured here, and subsequently, in folds), showing more or less equidimensional four to six sided cells set in no order or arrangement, and unmodified at margin. Stomata scattered in about equal numbers over both surfaces of leaf. Veins not or scarcely marked in cuticle either by cells modified in shape, or by non-stomatiferous zones. Epidermal cells having outlines 1·5μ–6μ thick, not or only slightly sinuous, sinuosities formed by pits though cell outline with swollen parts of the outline between them. Cells about 23μ across (15μ–38μ). General cuticle surface flat or showing low solid papillae ; sometimes thin areas of cuticle or a system of radiating fine lines present over each cell.

Stomata monocyclic, showing no preferred orientation, subsidiary cells consisting of a ring of four to seven (usually five) subsidiary cells with strongly thickened radial cell outlines, and often whole ring of cells forming very strongly cutinised unit. Guard cells very weakly cutinised, sunken in a pit formed by the overhanging subsidiary cells. Each subsidiary cell bearing solid cutin lappet on its dorsal surface very close to stomatal pit. Lappets varying much in size, usually directed somewhat upward and also forward over (often about closing) stomatal pit.

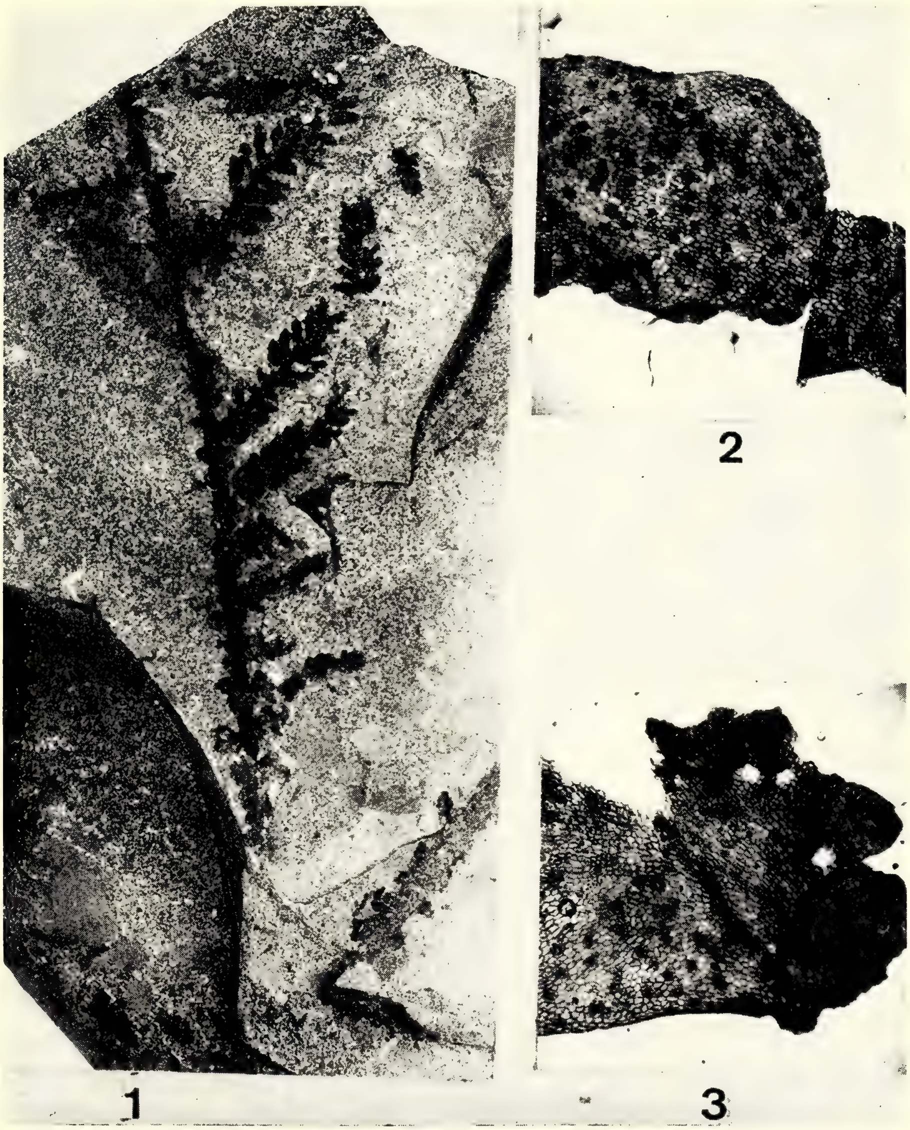
Rachis showing wide lumps, up to 2 mm. in diameter, sometimes paired, a pair occupying whole width of rachis. Lumps low showing only two or three rows of compressed cells round their margins, and (probably) never overhanging one another. Trichomes (as in other species) present but rare.

Description. The material examined consists of F12694 (Part and counterpart) Geological Survey N.S.W. from the Balmain Shaft, Sydney ; other leaves collected by Mr. R. Helby and myself at Turrimetta Head, one mile North of Narrabeen, N.S.W., now deposited in the University of Sydney, Department of Geology ; and further more fragmentary but more abundant material collected by my wife and me at Turrimetta Head on a subsequent occasion. Figured material of this collecting along with material collected at Coal Cliff, N.S.W., is in the Australian Museum. The Turrimetta Head material comes from the Upper Narrabeen (Raggatt in McElroy, 1962), and is, on the usual scheme of dating, uppermost Lower Triassic.

No leaf is complete, F12694 (pl. 1, fig. 1) is the most nearly so, and none show the base. However, as in other species of *Lepidopteris*, the pinnae and pinnules are borne close to one surface of the rachises, sometimes being overlapped at their bases by the compressed rachis (figs. 2*a*, *b*). In *L. stormbergensis* where there were leaf bases available, the pinnae are borne on or near the upper (adaxial) rachis surface, and it is by analogy with *L. stormbergensis* that the leaves of *L. madagascariensis* are orientated. This question is of importance in the matter of stomatal distribution and possible ecology.

Observed directly, the rachis shows wide but low lumps, varying greatly in size. At one extreme (fig. 2*a*) the lumps each occupy about half the width of the rachis, and their compressed edges stand out : at the other the rachis may be nearly smooth, and the lumps seen only with difficulty, for they are obscured by longitudinal compression folds. This situation is seen on the pinna rachis. On the parts of two leaves (Colls. of Sydney University), the lumps are paired, or sometimes paired, each pair apparently being connected below. This point is of interest for comparison with *L. martinsii*. Though there is fairly good evidence that the lumps on the rachis originate beneath a trichome, there is no evidence as to what caused the paired arrangement of the original trichomes, and whether paired or not, the lumps, so far as can be seen, are of the same sort (pl. 1, fig. 3 ; fig. 3*e*, and Townrow, 1960, fig. 2). The paired arrangement might be merely accidental—there is no room for more than two on one side of the rachis. On the rachis cuticle the somewhat concentric pattern of cells seen on the other species is present, and in a few places the trichome beneath which the lumps form (fig. 3*e* and see Townrow, 1960, pp. 336–340). When compressed, however, the lumps contrast strongly with those of *L. ottonis* (Goepp.) Schimp., for only a few cells at their margins are crushed (compare pl. 1, fig. 3 and Antevs, 1914, pl. 1, fig. 5). This confirms that by comparison with *L. ottonis*, the lumps are small.

On one leaf (fig. 2*b*) the lower rachis surface shows the remains of tufts of pinnules, which pass into the zwischerfiedern. On F12694 such tufts are definitely absent, on F51729 they may be present, but the rachis is broken and the situation obscure. On all leaves showing the zwischerfiedern clearly the basiscopic one arose on, or nearly on, the lower (abaxial) leaf surface,



Explanation of Plate

PLATE I—*L. madagascariensis*

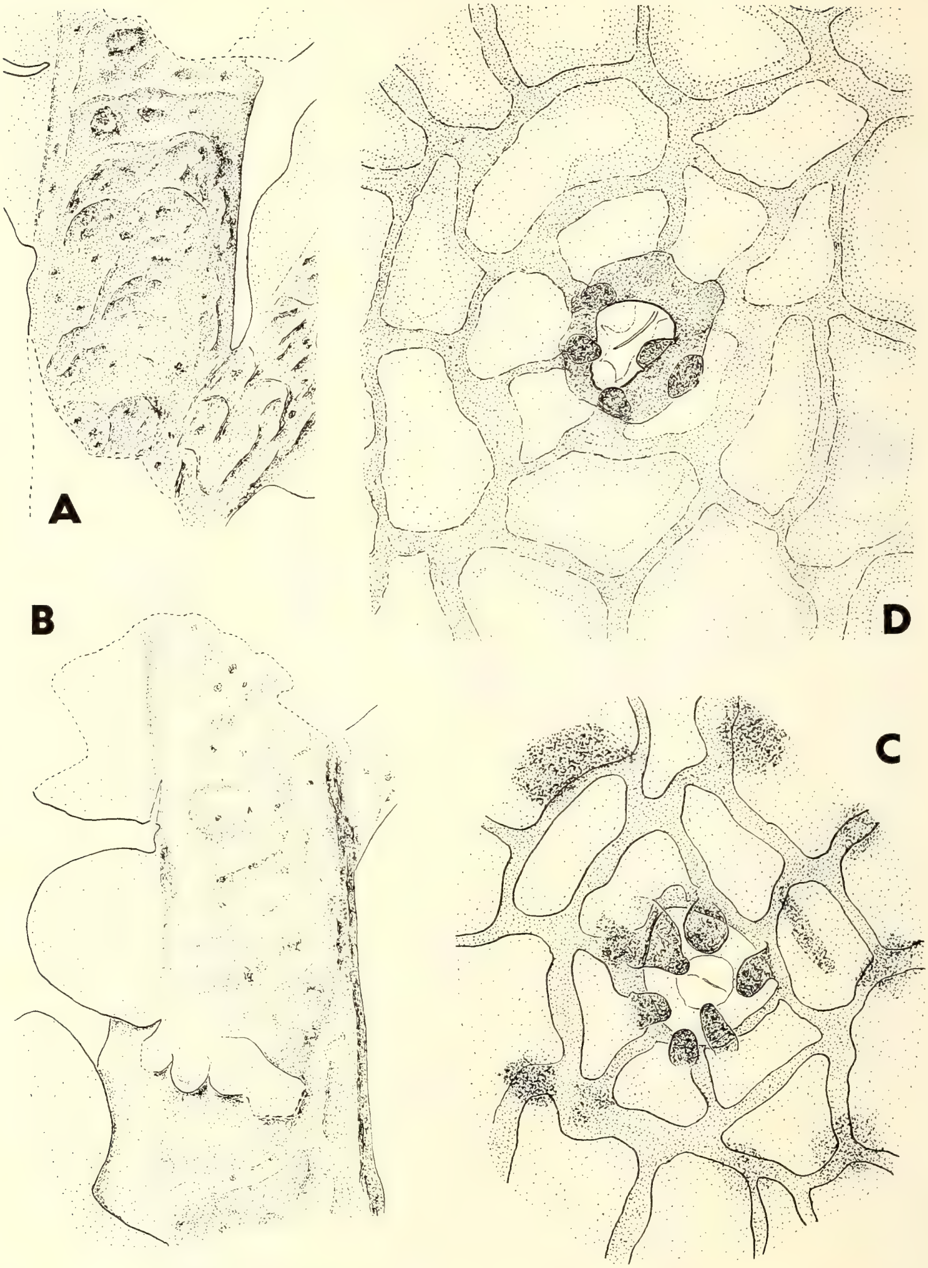
FIG. 1.—The most complete leaf available, F12694, $\times 0 \cdot 75$.

FIG. 2.—Lower cuticle, showing cell and stomatal arrangements (note, veins not visible). F51726, $\times 25$.

FIG. 3.—Part of a rachis and adjacent pinnule, showing compressed edges of the lumps. F51726, $\times 25$.

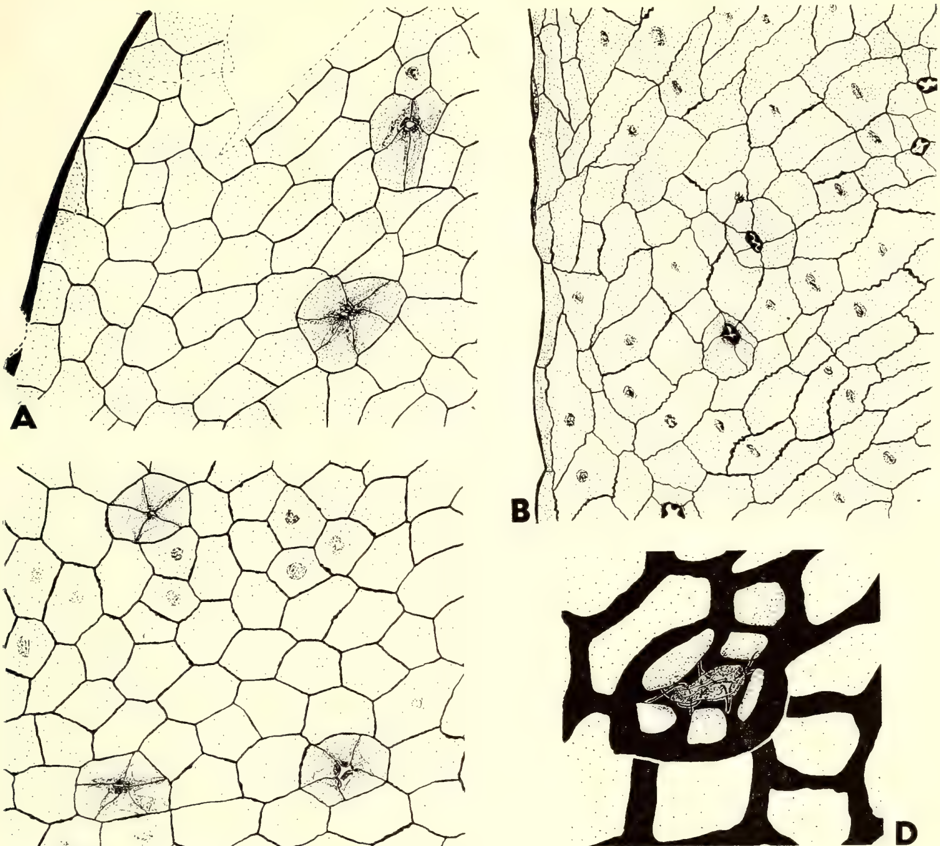
Explanation to Figures

TEXT-FIG. 1
Lepidopteris madagascariensis, form of leaf and venation. A. F51726. B. University of Sydney. C. F51728, Turrimetta. D. F51730, Coal Cliff, ×2. E. University of Sydney. F. F51729. G. F51727, Turrimetta, ×1.



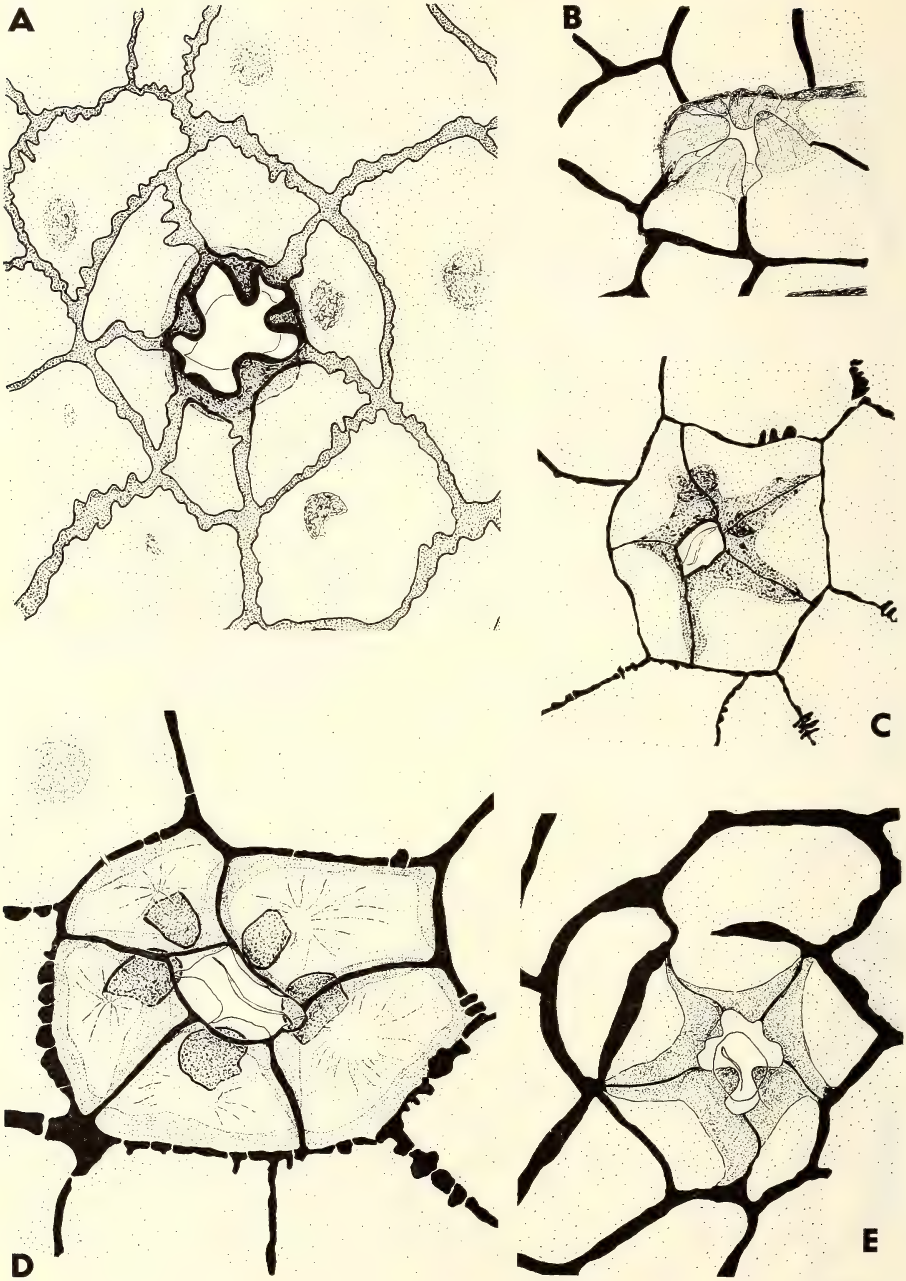
TEXT-FIG. 2

L. madagascariensis, A–C : *Thinnfeldia callipteroides*, D. A. Adaxial rachis and pinna rachis surface, showing form of lumps. University of Sydney, ×10. B. Abaxial rachis surface, showing insertion of zwischerfiedern, and remains of a tuft of pinnules on the rachis surface. University of Sydney, ×10. C. A stoma from the rachis with large cutin lappets and an irregularly dicyclic stoma. F51731, ×650. D. A stoma and surrounding cells note cutinisation round stomatal pit, and border to cell outlines. Oakdale State Colliery, Burragorong Valley, ×650.



Text-fig. 3

***L.** madagascariensis*, A, C–F : *L. stormbergensis*, B. A., C., F. cuticle (F lower leaf surface) showing arrangement of cells and stomata, in A including margin. A. F51729, C. University of Sydney, F. F51731, ×100. B. cuticle at pinnule margin, note narrow cells at margin, and vein at top, and bottom of fig. F378 (377), ×80. D. Stoma closed by cutin lappets, and with whole apparatus heavily cutinised, A.M. 6399, ×490. E. trichome from rachis, and slight profileration of cells round it, in a more or less radial pattern. University of Sydney, ×490.



TEXT-FIG. 4

L. madagascariensis, B–E ; *L. stormbergensis*, A. A. somewhat open stoma, irregularly dicyclic, with hollow papillae over stomatal pit, sinuous cell outlines, and low papillae. F378 (377), ×840. B. stoma compressed partly sideways, showing orientation of lappets, possibly as in life. University of Sydney, ×490. C., E. rather open stomata showing (*c*) sinous cell outlines only rarely seen in *L. madagascariensis*. F51730, F12694, ×490. D. a stoma, showing holes in more or less straight cell outlines, solid (?) upward pointing cutin papillae and lack of encircling cells. University of Sydney, ×840.

while the acroscopic one arose on the upper (adaxial) leaf surface. The lowest pinnule on a pinna was decurrent onto the main rachis (fig. 1*e*).

The form of the pinnules and variation is given in the diagnosis and shown in pl. 1, fig. 1 and figs. 1*a–g*.

Since the veins do not show in the cuticle, and are only seen with much difficulty on a few hand specimens, they can scarcely have projected in life. There are two alternative explanations. Either the leaves were thick, or the veins very small. There is no suggestion that the leaves were succulent, but I think it is quite probable that they were thick and leathery, for beside the evidence from the veins (as it is interpreted), the margin shows no modified cells, but there may be wrinklings in the cuticle, suggesting the compression of a rather thick organ. The absence of special marginal cells suggests that the leaf maintained the same thickness to the edge (fig. 3*a*).

The distribution of stomata is of considerable interest. In general, there is little difference between the two leaf surfaces in stomatal number (density and stomatal index). However in F12694 the cuticles are of different thicknesses, 3μ and 1·5μ, and the thinner cuticle is attached to the lower rachis surface (determined as above). Here, it is the thinner cuticle that has the more stomata (60/mm.^{2} : 40/mm.^{2}, S.I. 13·2 : 8·3). On another leaf, however, Colls. of Sydney University, orientated in the same way, it is the upper surface that shows more stomata (58/mm.^{2} : 69/mm.^{2}, S.I. 8·0 : 10·0).

The cuticle is shown in pl. 1, fig. 2 and figs. 3*a*, *c*, *f*. The cell outlines are usually straight, or with only the minutest projections, however, some specimens show what appear to be sinuous cell outlines. Examined under high magnification, the cell outlines show numerous narrow perforations, complete or nearly so, between which the outline swells out (fig. 4*d*). In this plant, therefore, the middle lamella is not sinuous. In the present material the veins are quite invisible on the cuticle; however, in one leaf now identified with *L. madagascariensis* (V/32106, see below) the veins do show as obscure rows of narrower cells (Townrow, 1956, fig. 3B).

Most stomata look like those figured in figs. 2*c*; 4*d*, *e*. The lappets do not show an area within themselves of lighter shade (*cf*. Townrow, 1956, fig. 4), and so are solid. In some specimens they project upwards, as seen by focussing. In most they probably projected upwards for fig. 4*b* shows a stoma compressed partly laterally, in which the lappets point upwards at about 45°; but stomata on this leaf compressed dorsi-ventrally *appear* to project only over the stomatal pit, which they largely close. With the orientation suggested for them, it is hard to see how the cutin lappets can have had much effect on transpiration. A few stomata in this as in the other species, lack lappets, their places being taken by a narrow rim of cutin (see Townrow, 1956, fig. 6B and fig. 4C).

Certain stomata (fig. 4*d*) show thick cutin bulges out onto the dorsal guard cell surface, the bulges corresponding to the edges of the subsidiary cells. In these, presumably, the dorsal wall of the guard cell, that it shares with the subsidiary cells, is more or less strongly cutinised. In other stomata, especially on those leaves with a thick cuticle, the whole area round the stoma is densely cutinised (fig. 3*d*). This cutin, from focussing, appears to extend far down the radial cell walls, so that there is an apparent interruption between the outward outline of the subsidiary cell, and the outlines of the other epidermal cells. As in *L. stormbergensis*, there is normally thickening on the subsidiary cells on the cuticle surface (Townrow, 1956, fig. 4 E, F).

One or two leaves (Colls. of Sydney University) show internally brown more or less circular masses, which do not dissolve in alkali. They may be resin.

Discussion of the specimens referred to L. madagascariensis. The material now identified as *L. madagascariensis* includes one leaf (V/32106) coming from Brookvale previously (Townrow, 1956) placed in *L. stormbergensis*. This leaf was recognised as unusual for *L. stormbergensis* having small pinnules, a thick cuticle showing straight or nearly straight cell outlines and only low (or no) papillae on the epidermal cells. It is not normal for *L. madagascariensis* either. It shows the course of the veins on the cuticle by files of elongated cells, and generally shows hollow papillae, not solid lappets over the stomatal pit. With hesitation this leaf is now reclassified as *L. madagascariensis*, since I think it diverges less from it than from *L. stormbergensis*.

It is now probable that the Queensland material referred by me (Townrow, 1960, p. 343) to *L. stormbergensis* should be reclassified. The specimen regarded as a pollen sac group of *Antevsia extans* (Fren uelli) comes from the

uppermost Beaufort Series, and so probably does not belong with *L. stormbergensis*, which as far as is known comes from the Molteno Group only (see du Toit, 1927, pl. 29, fig. 3 and Townrow, 1960, p. 352). However, this affects neither the nomenclature nor the ascription of other material to *A. extans*. The nature of du Toit's specimen is now left open.

Carpentier's (1935, 1936) material lacked a cuticle, but it shows a rachis having wide but low lumps, either paired (1935, pl. 3, fig. 4) or paired and alternate (1936, pl. 5, fig. 4), rather well separated pinnae and parallel sided obtuse pinnules. Thus it agrees with the commonest sort of leaf in my material and differs from *L. stormbergensis*. Carpentier (1936, p. 11) says that his material is perhaps identical (" est peut-être la même ") with *L. stuttgardiensis* of Zeiller from Madagascar. This is highly probable, but Zeiller's material has never been figured.

Du Toit's (1927) *Lepidopteris stuttgardiensis* is removed from that species, as it has only small lumps on the rachis. In gross form and size it agrees closely with the present material. There is no cuticle.

No definite opinion is expressed on du Toit's *Callipteridium africanum* (1927, pl. 27) from the uppermost Beaufort Series, nor on Seward's (1908, pl. 4, fig. 2) leaf called *Thinnfeldia sphenopteroides* Seward. This material is all poorly preserved, and atypical in one way or another, for example it is unusually large. However, should Seward's leaf finally prove to be identical his name will have priority. The leaves shown by du Toit (1927, pl. 26) are much too large and are excluded.

There are a number of old records of *Alethopteris* (none figured) from lower in the Narrabeen Group (listed by Raggatt in McElroy, 1962, p. 13), especially from the Balmain Shaft. Much material from Balmain is in the Geological and Mining Museum, but I have failed to find these particular specimens. However, *L. madagascariensis* does occur in the Lower Narrabeen Group. Figs. 1*d*, 2*c*, 3*f*, 4*e* show specimens collected at the base of the cliffs North of Coal Cliff beach, and occurring in a shale some 15 feet below the conglomerate layers marking the base of the Bulgo Sandstone ; they thus lie at the top of the Stanwell Park Shale (see Hanlon, Osborne and Raggatt, 1953). The material is variable, and fragmentary, but it corresponds with the younger leaves at every available point: the only possible difference being that the stomatal pit may overhang the guard cells less than in the Turrimetta Head leaves. There does not seem to be any reason why the Stanwell Park material should not be identified.

When in fragments, *L. madagascariensis* could be confused with the leaf *Thinnfeldia callipteroides* Carpentier (1935) with which it is sometimes associated. Indeed, I think this has happened and that some of the " *Alethopteris* " of the older records is *T. callipteroides*. Given complete leaves, there need be no confusion, *T. callipteroides* branches several times in a rather irregular way (see Carpentier, 1935, pl. 3, fig. 1) and, as far as known, the rachis of *T. callipteroides* is smooth. The cuticles are superficially similar, but (i) *T. callipteroides* has a thicker cuticle, 10μ or more in folds ; (ii) the cell outlines are thick and often show a sort of border absent in *Lepidopteris* (fig. 2*d*), and (iii) the stomatal pit is bounded by a massive cutin structure, recalling the cutin rim of some species of *Ctenozamites* Nathorst (Harris, 1964, p. 89), which is sometimes produced into (probably upward pointing) papillae, (fig. 2*d*). The further delimitation and affinities of *T. callipteroides* are left entirely open for the present.

Comparison of the species of Lepidopteris. The two Southern Hemisphere species, *L. stormbergensis* and *L. madagascariensis* can be distinguished as follows (see Townrow, 1956, 1960) :

	L. stormbergensis	*L. madagascariensis*
1.	Thin leaf substance	Thick leaf substance
2.	More or less pointed pinnules	Mostly obtuse pinnules
3.	Irregularly placed lumps on the rachis	Lumps on rachis often (not always) paired
4.	Distinctly sinuous cell outlines, unpierced by holes	Cell outlines straight, or minutely sinuous, often pierced by holes
5.	Irregularly dicyclic stomata, the stomatal pit being (mostly) overhung by hollow papillae	Stomata monocyclic, the stomatal pit being (mostly) overhung by solid cutin lappets
6.	Leaf margin thin, epidermal cells over margin elongated.	Leaf margin unmodified.

The three Northern species are unequally known and so rather difficult to treat. The Type species *L. stuttgardiensis* (see Townrow, 1956, for further references) from the Schilffsandstein of the German Keuper is only known as casts lacking detail. In outline the leaf is like *L. madagascariensis*, but shows the imprints of large to very large irregularly placed lumps on the rachis. *L. ottonis* (see Antevs, 1914, Harris, 1932) has a thick leaf substance, but more or less pointed pinnules, large to very large irregularly placed lumps on the rachis, and on the cuticle the veins are generally visible as files of elongated cells. *L. martinsii* (see Townrow, 1960) comes close to *L. madagascariensis*, but can be distinguished because it is often tripinnate, the lumps on the rachis are large and it lacks perforated cell outlines.

It must be emphasised, however, that the five species of *Lepidopteris* form a very close knit group. The difference just discussed will separate most specimens (about nine out of ten), but there is intergrading and will probably always be specimens whose classification is doubtful, especially among poorly preserved material.

Discussion

1. *The possible ecology of Lepidopteris and its evolution.* There is some evidence that *Lepidopteris* belonged to an herbaceous plant. A cutinised, hence primary, stem has been ascribed, on evidence of association and anatomical resemblance, to *L. ottonis* (Harris, 1932) and *L. stormbergensis* (Townrow, 1960). In addition, in *L. stormbergensis* it was found (Townrow, 1960, pp. 343–344) that some leaves showed more stomata on the upper leaf surface than on the lower; while other leaves had the opposite stomatal distribution. It was also found that in some waterside herbs (but not in trees) a similar pattern of stomatal distribution was present. Those leaves with more stomata on the upper leaf surface come from the lower nodes, those with more stomata on the lower leaf surface came from the upper nodes. It is now found (above p. 209) that some leaves of *L. madagascariensis* have a stomatal distribution like *L. stormbergensis*.

Against these facts, which seem to point towards an herbaceous plant, there are two which point towards a woody plant. In *L. ottonis* there is not the stomatal distribution just discussed for *L. stormbergensis*. The lower leaf surface, apparently generally, shows the majority of stomata. The cuticles of *Lepidopteris* are usually thick (3μ): this can be matched among plants growing in wet places today, especially in the Ericaceae and Epacridaceae, but these plants are woody, though often of low stature. The force of this analogy is open to some question, and I think the points suggesting an herbaceous habit are the more impressive.

Those facts bearing on the relationships of the Peltaspermaceae, whose leaf is *Lepidopteris*, have been discussed earlier (Townrow, 1960, pp. 358–359). The information now available for *L. madagascariensis* adds nothing to that discussion.

However, *L. madagascariensis* serves to tie in to the Upper Permian *L. martinsii* much more closely with the rest of the Family. *L. martinsii* and *L. madagascariensis* resemble one another, and together differ from the other species, in having paired lumps on the rachis, lateral veins in the pinnules that are (usually) unforked, and a stomatal structure that appears indistinguishable to me.

The ages of the *Lepidopteris* leaves are as follows (see also Townrow, 1960):

L. martinsii	Upper Permian	Northern Hemisphere
L. madagascariensis	Lower to Middle Triassic	Southern ,,
L. stormbergensis	Middle and Upper Triassic	Southern ,,
L. stuttgardiensis	Keuper	Northern ,,
L. ottonis	Rhaetic	Northern ,,

The lumps on the rachis probably arise by proliferation of the sub-epidermal cells beneath a trichome (Townrow, 1960, pp. 340). In *L. martinsii* the lumps so formed are large and often paired. In the two Southern species the lumps are small, sometimes absent in *L. stormbergensis* but *L. madagascariensis* may retain the paired arrangement. In the two Triassic Northern species the lumps are large but irregular.

The tufts of pinnules on the rachis lower surface, seen in *L. martinsii* are retained in both Southern species (at least on some leaves): they are not seen on *L. ottonis*, while in *L. stuttgardiensis* the preservation is too poor to say with assurance that they are absent, but none of the figures suggests their presence.

The stomatal structure of *L. martinsii* and *L. madagascariensis* is very close (fig. 4*d* and Townrow, 1960, fig. 35). *L. stormbergensis*

shows hollow papillae, but *L. ottonis* retains the solid cutin lappet. However, it generally lies not on the dorsal cell surface, projecting upwards, but on the edge of the stomatal pit, and projects (usually) horizontally (Harris, 1932).

Finally, *L. stormbergensis* unlike the other species (*L. stuttgardiensis* is unknown) has a rather thin leaf.

One explanation of the information just summarised is that there was parallel evolution in the Northern and Southern Triassic species of leaf; sometimes one group of species retaining a feature of the earliest *L. martinsii*, sometimes the other. This is of considerable interest for it suggests that: while the Family was Northern in origin, and reached the Southern continents in the Lower Triassic (like a good many other sorts of plant as Balme, 1963, shows), once established in each Hemisphere, the groups of species in each evolved with little (or no) reference to the other. That is, that migration from one to other Hemisphere was not maintained in the later Triassic. If, with Roselt (1962), we regard *Callipterianthus anhardtii* Roselt as allied to the peltasperms, a similar conclusion emerges from the pollen organs. More information is needed to carry this speculation any further, or to decide whether the sort of behaviour suggested is found in other groups of plants.

2. *Southern Triassic floras containing Lepidopteris.* *Lepidopteris stormbergensis* is known from the Molteno Group of South Africa, and from the Hawkesbury Sandstone of New South Wales (Townrow, 1960, text fig. 5G). The Molteno Group has been dated as Middle Triassic, but the discovery of sauropods in it (Dr. J. Cosgriff pers. com.) places it in the Upper Triassic. The Brookvale shale lens lying near the top of the Hawkesbury Sandstone, is dated as Middle Triassic on its fishes by Wade (1935). No *Lepidopteris* has yet been found in the Rhaeto-Liassic (Dettmann, 1961) of South Australia or Tasmania: neither is it found in the Ipswich Coal Measures, though these are dated by Jones and de Jersey (1947) and de Jersey (1962) as Middle to Upper Triassic. It does, however, occur in the Esk Beds, whose top is equivalent to the base of the Ipswich Coal Measures.

Provisionally therefore, *L. stormbergensis* is called a Middle and partly Upper Triassic species. It does not, on present evidence, reach the Rhaetic, and may not enter the equivalent of the Norinic.

The *Lepidopteris* from the Hawkesbury Sandstone, though small in amount is very interesting. The leaf from the Brookvale shale lens has already been discussed (p. 6), since it comes intermediate between *L. stormbergensis* and *L. madagascariensis*. There is other similar material in the Geological and Mining Museum coming many years ago from a shale lens at Woolloomoolloo, also towards the top of the Hawkesbury Sandstone. Though all the specimens are given one number (F 388), there is so much variation that I think it likely that at least two leaves were originally present (M 426 and 429: M 411, 428, 377 and 378). These specimens too are intermediate between *L. stormbergensis* and *L. madagascariensis*. They show mostly papillate cells, many sinuous cell outlines, files of elongated cells over the veins and (in some) a thin leaf margin, and mostly hollow papillae over the stomatal pit (figs. 3*b*, 4*a*), characters of *L. stormbergensis*. However, they also show thick cuticles (5μ or more in folds), and in M 429 with M 426 the thin leaf margin is missing and at least half the stomata show solid lappets, and these are features of *L. madagascariensis*.

Three out of the four specimens from the Hawkesbury Sandstone are atypical and intermediate between *L. madagascariensis* and *L. stormbergensis*, and though one, V 32972 has typical characters of *L. stormbergensis*, none have typical characters of *L. madagascariensis*. This rules out the possibility that we are dealing with a mixture of the two species. Perhaps at this horizon *L. madagascariensis* is evolving into *L. stormbergensis*, or we may be dealing with a population distinct from either. With present knowledge, to describe it as a new species would merely confuse the taxonomy of *Lepidopteris*.

L. madagascariensis occurs in, and helps tie together, two Lower Triassic floras. One flora, with abundant *Dicroidium* and other forking leaves, is well seen in du Toit's (1927) South African flora from Brown's River. It is also seen in Walkom's (1925) flora from Turrimetta Head, towards the top of the Narrabeen Group. The Brown's River flora occurs in sandstone at the top of the *Cynognathus* zone of the Karroo tetrapod zones, and is thus uppermost Lower Triassic. The Narrabeen flora cannot be extrinsically dated, but is usually given also as uppermost Lower Triassic.

The other flora is seen in Carpentier's (1935, 1936) Sakamena flora, the Sakamena being placed by Lehman (1952, pp. 190–196; 1961, pp. 151–152) at the base of the Triassic. In

this flora *Dicroidium* is almost or quite absent. In Australia a flora showing much in common with Carpentier's appears in the roof shales of the Bulli Seam, also lacking *Dicroidium*, also basal Triassic (Hennelly, 1958). *Lepidopteris* is not known from the Bulli flora. The oldest record of *L. madagascariensis* is the one referred to above from the Stanwell Park Shales (upper Lower Narrabeen Group). Here it occurs with *Thinnfeldia callipteroides* Carpentier—common in the Bulli roof shales—*and* leaf fragments with a *Dicroidium*-like cuticle. This statement ignores even older records that may be of *Lepidopteris*, but in absence of figures or material, and in view of the fact that the concept of all the species involved has altered since the records were made, one must ignore these records.

The interesting fact thus emerges that in New South Wales, and Madagascar, there is a basal Triassic flora which, unlike floras from the later Triassic, is not dominated by the Corystospermaceae. By the top of the lower Triassic, however, the Corystospermaceae had become dominant, as at Turrimetta Head and Brown's River. It is not possible to say yet when one flora changed into the other, and this information is much to be desired. The discovery of *Dicroidium*-like fragments in the Stanwell Park Shales suggests that the basal Triassic flora without *Dicroidium* did not last long.

Contrary to Walkom (1925) but in agreement with Hennelly (1958) and Balme (1963) I can see very little of a *Glossopteris* flora in Carpentier's basal Triassic flora, or in material from the Bulli roof shales. It is conceded that the occasional specimen of *Glossopteris* Brongniart or *Phyllotheca* Brongniart may be found, and *Schizoneura* Schimper and Mougeot is common to both. But the whole appearance of the flora, with its abundant conifers, *Thinnfeldia callipteroides* and (in Madagascar), *Lepidopteris* is quite unlike a *Glossopteris* flora.

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The Big Hole near Braidwood, New South Wales

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Abstract—A survey and observations of the Big Hole are regarded as supporting the view that it is a subjacent karst doline due to solution of inferred Silurian limestone lying unconformably beneath the ridge of Devonian sandstone and conglomerate in which it lies. Its combination of large size and a high depth width/ratio is exceptional for the landform type and a structural cause is invoked since it is probable that the limestone would occur as a narrow, steeply dipping strike belt. Sudden collapse of a çave roof in the limestone explains the Big Hole's characteristics better than gradual stoping of the sandstone through solution at the top of the limestone. The inference that the solution must have been deep phreatic in nature presents a problem for the formation of the large cave involved.

The Big Hole is a deep pit which abruptly interrupts the wooded north-eastern flank of a ridge about half a mile east of the Shoalhaven River 20 miles south-south-west of Braidwood in the Southern Tablelands. Recent descents by the Canberra Speleological Society have been made the occasion of measuring its dimensions and making other observations which bear on the origin of this remarkable feature.

General Description

It is a pit of angular plan with a maximum diameter of 175 feet and a minimum of 100 feet at right angles.[1] Since the hillslope in which it is set is steep, there is a difference of about 50 feet between the highest south-western part of the lip of the pit and the lowest north-eastern part. The depth from the highest lip to the lowest part of the pit is 360 feet whereas the depth from the lowest lip to the floor beneath is 240 feet. Although the Big Hole opens near the top of the ridge, its bottom reaches a level some 80 feet below the gently inclined and marshy valley floor to the east.

Most of the way down, the walls are nearly vertical to slightly overhanging, with occasional small ledges and overhangs in the bedding planes. Below the eastern corner there is a vegetated slope about 100 to 120 feet down. Near the bottom greater overhangs have developed on the north-eastern side and, most of all, on the south-western side where there is a large recess some 60 feet deep and 80 feet high. The maximum and minimum diameters at the base are 240 and 120 feet respectively.

Parts of the walls appear from weathering stains on the surfaces to be in a fairly stable condition ; this is notably so on part of the south-western wall where the safest descents can be made. From fresh rock surfaces and opened joints, other parts of the walls appear to be undergoing active rockfall and along about 20 feet of the north-eastern wall, fissuring a few feet back from the lip indicates that a large mass will break away before long. However, a number of eucalypts up to 18 inches in diameter are growing so closely to the walls at various points round the perimeter as to bear witness to stability since they began to grow.

The floor consists entirely of a rubble pile some 80 feet high, with a more gently sloping upper part at angles of 20–25° and a longer steeper slope at about 35° beneath the south-western overhang. The total depth of rubble is unknown. The blocks are larger towards the sides were they reach to four feet in length. In the south-west, boulders are jammed against the wall to form a small cave about 20 feet long. At the lowest part of this south-western corner there is standing water, which on 14 May, 1961, was up to six feet deep, and fine silt on the rocks around indicated it had recently been as much as five feet deeper. The rubble pile is elongated more or less parallel to the longer axis of the hole but eccentrically disposed away from the higher southern walls. A cover of tree ferns about six feet high of the top of the pile confirms the inference that there has not been a major fall from the walls for many years.

[1] The rough dimensions given by Trickett (1900) tally very well with these measurements whereas those on the face of the relevant map in Carne and Jones (1919) depart substantially from them.

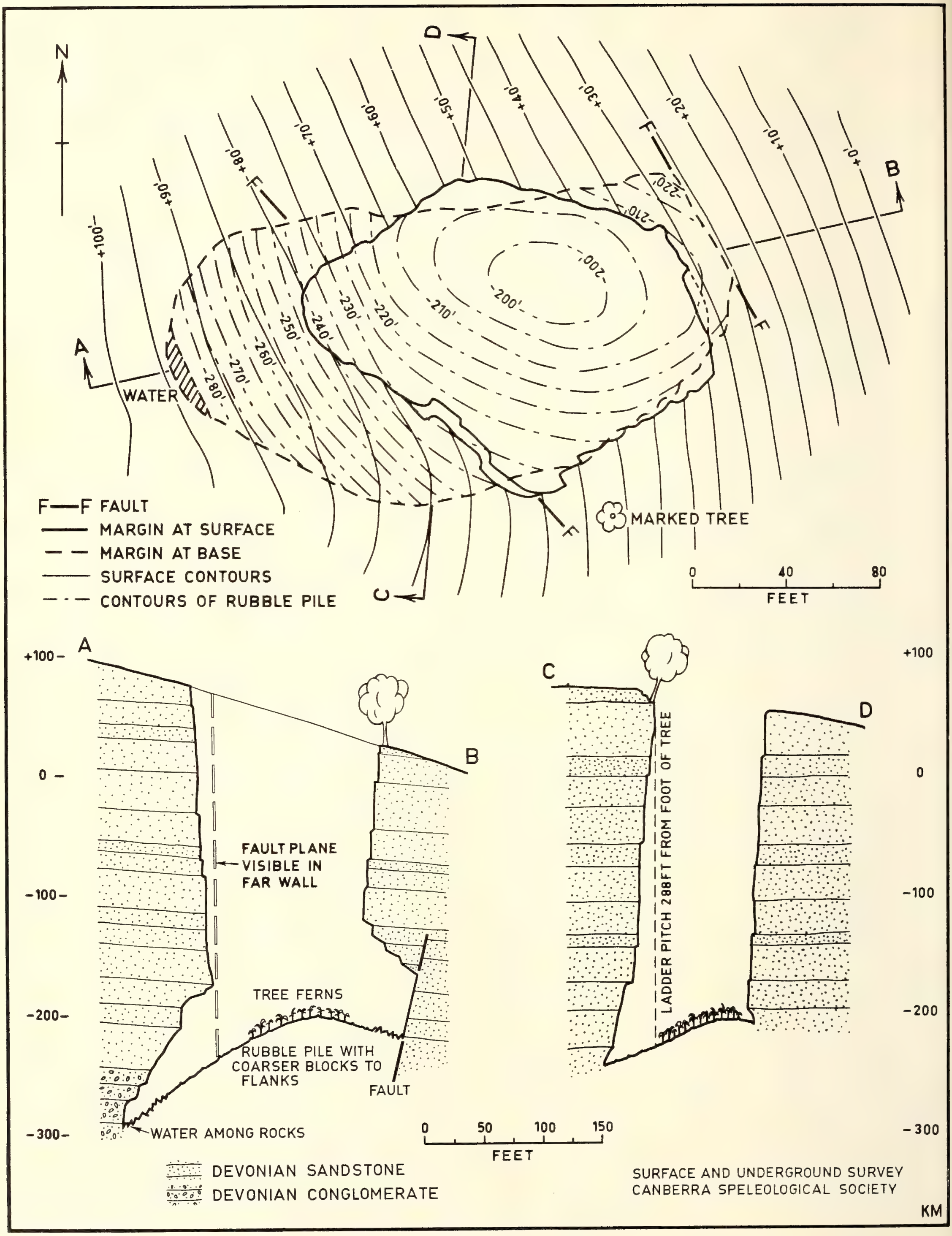

FIG. 1
Plan and cross-sections of The Big Hole near Braidwood, New South Wales. Note that the cross-sections are at a smaller scale than the plan. The datum for heights is arbitrary.

Geological Features

The surrounding hill and the Big Hole from top to bottom consist entirely of Devonian rocks ; most of the walls are quartzitic sandstone, mainly very thick-bedded, but the lowest part of the south-western wall is conglomeratic. The attitude of the beds seems to be nearly horizontal in general but there is a gentle roll over the hole, to be seen most clearly in the south-eastern wall. Two nearly vertical faults, throwing a few feet only, occur in the hole, one in the backwall of the north-eastern overhang and the other coinciding with part of the south-western wall and clearly visible in the full height of the north-western wall. Narrow brecciated zones up to four feet thick mark the faults and major joints are parallel of them.

Discussion

Though the data given above do not prove, they give support to the contention that the Big Hole is a feature of subjacent[2] karst development (*"unterirdische Karstphänomen"* of Penck, 1924) ; solutional removal of a more soluble rock below has caused a surface depression through subsidence of overlying insoluble[3] rock.

Other hypotheses fit the known facts less well or require less probable postulates about the underlying geological structure. Volcanic explosions and meteoritic impacts produce craters of bowl-like form quite unlike the cavity in question. Also its compact horizontal combined with pronounced vertical development is out of keeping with a tectonic origin ; if faulting produces a surface cavity, it is of fissure type and there are usually associated surface manifestations of faulting not found here. Subsidence depressions can be caused by oxidation of sulphide ore bodies (Wisser, 1927) and the forms produced are more akin to the features under discussion. However, the regional geology offers no support for postulating such bodies.

Features broadly similar to the Big Hole are known to be due to various subjacent karst rocks—gypsum and highly soluble evaporites such as rocksalt and potash as well as the more widespread carbonate rocks, dolomite and limestone. However, evaporites are not known from the Palaeozoic rocks of the area and the nearest dolomites are in the Buchan area of Eastern Victoria. Although no limestone is found in the Big Hole, the occurrence of Silurian limestone unconformably beneath basal Devonian conglomerate at Wyanbene five miles south-south-east and recurring at Marble Arch and Cheitmore in the same line of strike passing two miles east of the Big Hole points to limestone being the karst rock responsible for the latter. Carne and Jones (1919) had no hesitation in assuming this to be the case, even though it does leave some geomorphological difficulties which will be discussed below. The structural difficulty that a second strike belt of limestone, additional to the one which outcrops on a line to the east, must be involved in the formation of the Big Hole makes little demand in this context of closely folded lower Palaeozoic rocks ; Silurian limestones in parallel strike belts only a few miles apart are known elsewhere in the Southern Tablelands.

As a subjacent karst doline, the Big Hole is far from rare. Nevertheless on the basis of some of the more readily available relevant literature (Bennett, 1908 ; Cramer, 1941 ; Fisher, 1859 ; Hare, 1947 ; Laurence, 1937 ; Lee, 1926 ; Stockdale, 1936 ; Thomas, 1959, 1963), it is an exceptional case in its combination of considerable absolute size with pronounced vertical development. The depth/width ratio is 2 : 1 on the basis of the maximum surface diameter and 3·5 : 1 on the minimum.

The examples discussed by Fisher (1859) and Hare (1947) are shallow (40–60 feet deep) and basin- or funnel-shaped rather than pit-like, with D/W ratios between 1 : 18 and 1 : 3·5. Both authors deal with areas where thin Tertiary beds overlie Cretaceous Chalk in south-east England. However, the thinness of overlying rocks cannot be expected to limit depth in relation to width because there is no structural reason why the surface depression in the insoluble rocks should not be continued downwards into the underlying karst rock. Moreover recent discussions by Thomas (1959, 1963) of solution subsidence phenomena in Carmarthenshire and Breconshire in Wales suggest that thickness of cover rocks has little control of doline shape. Here dolines tend to be larger and steeper in the overlying Millstone Grit than in the exposed parts of the underlying Carboniferous Limestone. But depths remain rather small—up to 60 feet and D/W ratios low, even though the Grit reaches thicknesses of 450–550 feet. The dolines do

[2] "Subjacent" (cf. Martin, 1965) is used in preference to "covered" since the latter term is more closely associated with thin covers of superficial deposits and/or soils.

[3] The cover rocks are, of course, not completely "insoluble" but this slight lack of precision is thought preferable to the use of such terms as "non-karst" or "unkarstifiable".

not change in character as the Grit gets thicker. One figure (Thomas, 1959) shows a very steep-sided doline 75 feet across and 45 feet deep, giving a D/W ratio of 1 : 1·7 however. Greater thicknesses still of covering rocks are recorded from the Cumberland Plateau in Tennessee in U.S.A. where up to 800 feet of sandstone and shale overlie thick Mississippian limestone (Laurence, 1937 ; Stockdale, 1936). The largest doline described here is elliptical in shape, 390 by 250 feet, with a probable depth of 230 feet (Stockdale, 1936). These dimensions give ratios of 1 : 1·6 and 1 : 1·1, approaching more closely to the Big Hole values. The vertical rock walls and talus slopes up to 130 feet high of this doline surround a deep lake, Montlake. The presence of this lake suggests that depth to water rest levels is not a critical factor governing the shape of dolines any more than the thickness of the cover rocks.

Of all the authors consulted, Cramer (1941) alone records subsidence dolines with D/W ratios exceeding those of the Big Hole. A shaft near Gotha in central Germany opened up suddenly in the Muschelkalk to become 3–4 m. diameter and more than 37 m. deep (D/W > 12·3 : 1) and a similar subsidence near Zimmern in Thuringia produced a shaft 3–4 m. wide and 38–40 m. deep (D/W 13·3 : 1). However, not only are these examples smaller than the Big Hole, they are also not fully comparable on other grounds. The measurements were made at the time of subsidence when long-term stability had not been achieved. Thus the Zimmern example four years later on is described as remaining shaft-like below but having become a steep funnel shape above. Also older subsidences near Gotha were much wider with 1 : 2 to 1 : 3 ratios. Moreover, these occurrences were due to solution of the salt and gypsum beds of the Zechstein series and different effects can be expected from these more soluble rocks.

The Big Hole therefore appears to be an extreme case in its form. A structural cause seems possible because in all the examples cited above the limestones as well as the cover rocks were not far from horizontally disposed, whereas in the case of the Big Hole it is reasonable to infer from the regional geology that the limestone involved would be steeply dipping or vertical in attitude and so of great depth but in a strike belt of little width. In the former cases subterranean solution would not be confined laterally and might tend to remove extensive but shallow bodies of limestone, inducing basin-like depressions. In the latter case solution might be concentrated in horizontal dimensions but able to work in great depth. Sharply confined but deeper subsidence could be the consequence. The presence of the two faults in the Devonian rocks above, crossing the probable line of strike of the limestone at an angle, might localise and facilitate the subsidence.

In his general review of dolines, Cramer (1941) discusses those involving the subsidence of overlying insoluble rocks in two categories, respectively named *Erdfälle* (sink holes) and *Schwunddolinen* (swallow holes) or *Nachsackungsdolinen* (subsidence dolines). The first category is attributed to sudden collapse into a cave in the underlying karst rock and resemblance to collapse dolines (*Einsturzdolinen*) in outcropping karst rocks is close. In thick resistant cover rocks, deep pits may be produced by subsidence into large caves and these may retain steep walls for decades, until weathering eventually produces first a funnel and then a basin shape. The second category is described as due to gradual subsidence or to cumulative effects of subsidence at intervals through progressive subcutaneous solution. The solution in this category is thought to take place at the top of the karst rock, inducing more or less continuous stoping of the cover rock but without the development of large cavities. The resemblance therefore is to the solution dolines (*Lösungsdolinen*) of outcropping karst rocks.

Greater opportunities for weathering should result in the second category becoming more regularly shaped dolines with less steep sides earlier in their history than in the first category. Moreover their sides may become composite in nature, reflecting several phases of development rather than one catastrophic event more or less instantaneous in a geological time scale.

The angularity of plan of the Big Hole, together with its great D/W ratio and uniformly steep walls from top to bottom, constitutes a strong case for placing it in the first category. This ascription must be recognised as demanding the formation of a very large chamber in the limestone, much larger than any known in the neighbouring exposed karsts.

Major subsidence would not, however, produce the smooth shape and size sorting of the debris pile in the Big Hole. This must be due to subsequent small-scale accretion from the walls of the pit. Bouncing of fragments from the walls in the long descent would account for the absence of a raised rim around the debris pile at the foot of the walls such as is often found in shallower dolines, and also for the fact that the top of the pile is displaced away from the

higher southern walls, which can be expected to have supplied the greater volumes of material. The flatter top of the pile with slopes lower than the angle of rest for talus is probably due to the scatter resulting from ricochet.

From the presence of standing water at the bottom, the limestone solution regarded as causing the doline must have taken place below the present groundwater level. Furthermore it is difficult to envisage how past water levels can have been significantly lower than at present, even though the vicinity of the Big Hole has not been affected by the coastal slope rejuvenation, which is now lowering water levels in the limestone at Marble Arch and Cheitmore not far to the east. The valleys around the Big Hole ridge drain to the upland plain of the Shoalhaven, part of the Newer Peneplain of Tertiary age of Craft (1932). There is no great aggradation in this plain near the Big Hole to allow of former lower groundwater levels. The hidden limestone mass beneath the ridge is likely to have been small, below the level of nearby surface drainage and barred round by impervious rocks. In these circumstances the solution below the Big Hole must have been phreatic in nature and true phreatic rather than epiphreatic or shallow phreatic.

The volume of the Big Hole is of the order of 3,200,000 cubic feet but as the loss of sandstone from the system seems unlikely in view of the previous discussion, the volume of limestone removed in solution to accommodate the shattered subsided rock with its voids must have been significantly larger by a margin which is difficult to estimate. The recent tendency in speleological theory, both in Europe and North America, has trended against attributing large caves to deep phreatic solution. Bretz's interpretation of Carlsbad Cavern with its exceptionally large Big Room as of deep phreatic origin has not been controverted yet, however, even though the occurrence of several horizontally developed levels in that system appear to be a difficulty for it. The amount of deep phreatic solution demanded by the interpretation of the Big Holes' origin supported here remains a difficulty for this view.

Even if we accept a single catastrophic subsidence as the mode of origin of the Big Hole, it is still difficult to ascribe an age to it. Historical knowledge of it and the inferences from the vegetation around and within the hole mean that it is at least a century old. Beyond that, its freshness of form implies great youth geologically but datings of analogous dolines are not available to translate this freshness into so many centuries or millennia. The fact that part of limestone shafts such as Padirac in France can be regarded as surviving from the Lower Tertiary (Cavaille, 1963) is a warning against uncontrolled speculation in this matter.

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Petrography of Some Permian Sediments from the Lower Hunter Valley of New South Wales

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Abstract—The non-coal detrital sediments of the Tomago and Newcastle Coal Measures in the Lower Hunter Valley comprise a homogeneous lithological suite ranging from fine-grained rudite to claystone. Lacustrine conglomerates and fluvial sandstones are moderately well-sorted lithic (volcomictic) types, with recrystallized mixed-layer mica-montmorillonite/kaolinite matrix-cements. For the rudite-siltstone range, the ratio rock fragments : quartz/feldspar appears to be a direct function of average grainsize. Reworked deltaic arenites (e.g. Waratah Sandstones) have comparable compositions, but are typically better-sorted and more compact than their fluvial counterparts. The marine Ravensfield and Cessnock Sandstones and their siltstone variants are well-sorted, compact rocks, which contain less lithic detritus and correspondingly more quartz and feldspar than the coal measures arenites.

Textural characteristics suggest a possible genetic link between the massive clayey siltstones and interlaminated siltstone/claystone lithologies of the deltaic environments.

Montmorillonite and kaolinite are the chief constituents of the marine claystones studied. Clay rocks of the Tomago and Newcastle Coal Measures may have similar clay mineralogies, but more commonly contain mixed-layer mica-montmorillonites in lieu of montmorillonite. Erratic glacial and volcanic debris occur in some claystones.

Bentonites from the Tomago and Newcastle Coal Measures are highly montmorillonitic. Variable particle-size and plasticity characteristics of these materials reflect differences in the physical properties of the clay mineral constituents.

Introduction

Earlier studies on the geology of the Permian System of the Hunter River Valley, New South Wales (David, 1907 ; Raggatt, 1938 ; Jones, 1939) in general have included little detailed petrological and mineralogical information pertaining to the non-coal sediments. Booker, Bursill and McElroy (1953) have described the petrographic properties of the rocks outcropping in the Singleton-Muswellbrook region, and in a later work Booker (1960) has provided mineralogical data for some Permian bentonite deposits of the Newcastle area. A wider mineralogical survey of the Permian economic clay deposits of the Hunter Valley has been made by Loughnan (1960). Specific aspects of clay mineralogy have also been covered in subsequent papers (Loughnan and See, 1959 ; Loughnan and Craig, 1960). The heavy mineral suites of the coarser clastic lithologies of the Hunter Valley succession have been studied in detail by Culey (1938) and Carrol (1940).

The work reported herein represents part of a comprehensive lithological study recently carried out by the author on sediments from the Lower Hunter Permian type succession. Materials from the Tomago and Newcastle Coal Measures have been examined in detail and are here compared with some typical lithologies of the associated marine groups.

Geological Setting and Stratigraphy

Outcrops of Permian sediments along the northern margin of the Sydney Basin are confined to the floors of the Hunter and Goulburn River Valleys (Fig. 1). To the south the gently dipping succession is overlain conformably by sediments of the Triassic Narrabeen Group, and to the north is separated from the deformed Palaeozoic " Central Complex " region (Voisey, 1959) by the Hunter-Mooki Thrust System (Osborne, 1950).

The Permian depositional environments of the Lower Hunter have been described by Booker (1960) as " marginal geosynclinal lacustrine and barred estuarine ", representing accumulations under glacial, effusive and explosive volcanic, as well as normal fluvial/deltaic and paludal swamp conditions.

In the Maitland-Cessnock-Newcastle region a type stratigraphic section, 14,000 feet in thickness, is exposed in and adjacent to the deeply eroded Lochinvar Anticline (Fig. 2). A recent reclassification of the succession by

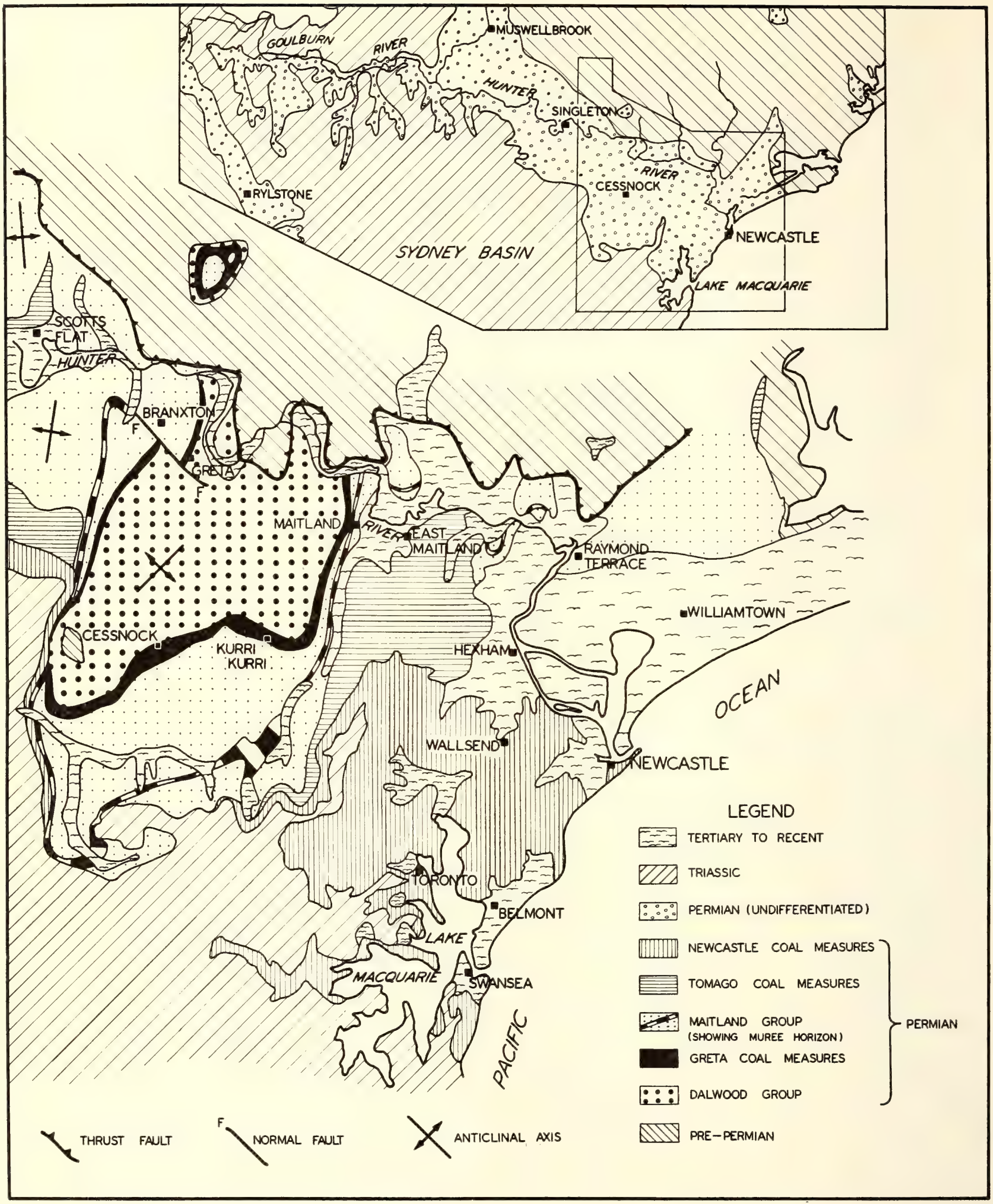

Fig. 1
Geological map of the Lower Hunter River Valley region (after Jones, 1939). Legend from Booker (1960).

Booker (1960) defines five stratigraphic groups, representing two major alternations of marine and freshwater deposition (Table 1). Discrimination between the Tomago and Newcastle units is based primarily upon distributional and lithological contrasts.

(*a*) *Dalwood Group*

Six thousand feet of Dalwood Group sediments are exposed in the core of the Lochinvar Anticline. The lower formations contain abundant andesitic tuffs and basalt flows, locally associated with tuffaceous arenites, claystones and boulder beds containing occasional horizons of glacial erratics. The upper formations contain finer, and better-sorted quartzose sediments (e.g. Ravensfield Sandstone), and are generally poorer in volcanic materials.

(*b*) *Greta Coal Measures*

The succeeding Greta Coal Measures consist of a succession of coals, rudites and arenites, 100–300 feet in thickness. Claystones are rare in the sequence.

(*c*) *Maitland Group*

The lower units of the marine Maitland Group are generally conformable with the underlying Greta succession. However, transgressional overlaps between the upper and lower Maitland beds, on the flanks of the Lochinvar Anticline, clearly mark the inception of Permian folding in the region. Booker (1960) has divided the Maitland sequence into two major subunits—the Branxton Subgroup (lower) and Mulbring Subgroup (upper). Four lithological subdivisions of the Branxton Subgroup are defined—viz. the basal Elderslie Formation (1,500 feet) comprising a sequence of predominantly arenaceous and conglomeratic rocks, associated with fossiliferous sandy lutites, containing glacial erratics; the succeeding Fenestella Shale (20–100 feet), constitutes a useful stratigraphic marker in the Lower

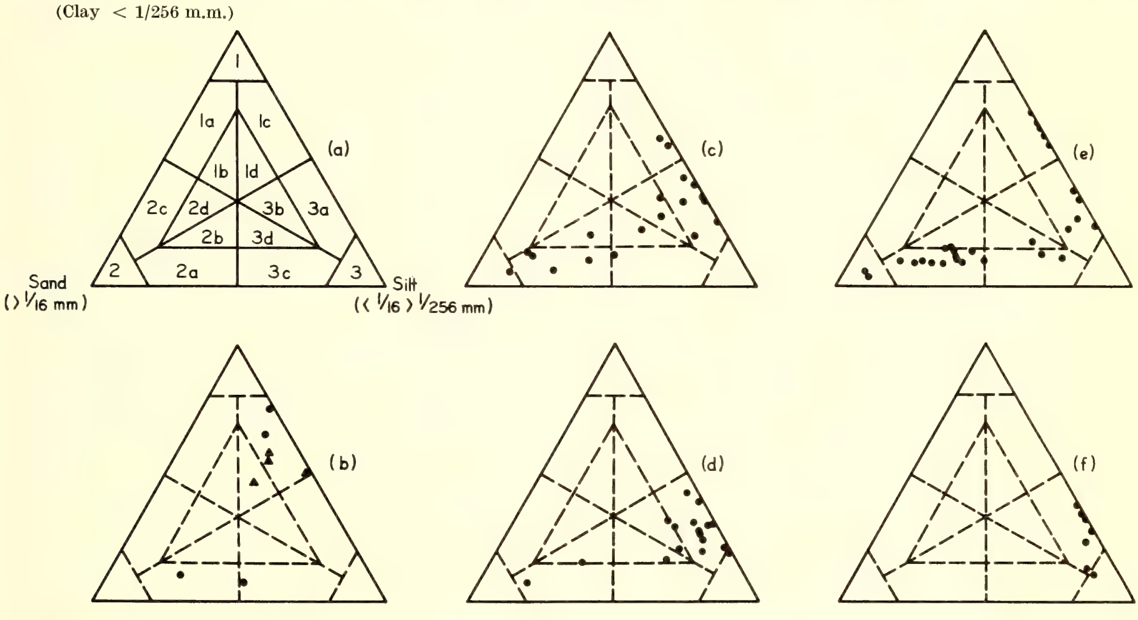

Fig. 2

Lithological classification of the Lower Hunter Permian sediments.

(*a*) Lithological classification (modified after Trefethan, 1950)

1—Claystone ; 1*a*—Sandy claystone ; 1*b*—Silty sandy claystone ; 1*c*—Silty claystone ; 1*d*—Sandy silty claystone.

2—Sandstone ; 2*a*—Silty sandstone ; 2*b*—Clayey silty sandstone ; 2*c*—Clayey sandstone ; 2*d*—Silty clayey sandstone.

3—Siltstone ; 3*a*—Clayey siltstone ; 3*b*—Sandy clayey siltstone ; 3*c*—Sandy siltstone ; 3*d*—Clayey sandy siltstone.

(*b*) ● Dalwood Group. ▲ Maitland Group.

(*c*) Tomago Coal Measures, pure lithologies.

(*d*) Tomago Coal Measures, interlaminated lithologies.

(*e*) Newcastle Coal Measures, pure lithologies.

(*f*) Newcastle Coal Measures, interlaminated lithologies.

TABLE 1

Permian Stratigraphic Succession of the Lower Hunter Valley

System	*Group*	*Subgroup*	*Formation*
TRIASSIC	Narrabeen	Clifton Subgroup 1,300′[2]	Munmorah Formation[3] (500′) with Wallarah Tuff Member
PERMIAN[1]	Newcastle[3] Coal Measures	Moon Island Beach Subgroup (250′)	Wallarah Seam
			Catherine Hill Bay Formation
			Great Northern Seam
			Eleebana Formation
			Fassifern Seam
		Boolaroo Subgroup (300–600′)	Croudace Bay Formation
			Upper Pilot Seam
			Reid's Mistake Formation
			Lower Pilot Seam
			Warner's Bay Formation
			Hartley Hill Seam
			Mount Hutton Formation
		Cardiff Subgroup (500′)	Australasian Seam
			Tickhole Formation
			Montrose Seam
			Kahibah Formation
			Wave Hill Seam
			Highfields Formation
			Fern Valley Seam
			Kotara Formation
		Lambton Subgroup (200–300′)	Victoria Tunnel Seam
			Shepherd's Hill Formation
			Nobby's Seam
			Bar Beach Formation
			Dudley Seam
			Bogey Hole Formation
			Yard Seam
			Tighe's Hill Formation
			Borehole Seam
			Waratah Sandstone (100′)
	Tomago[5] Coal Measures (1,200′)		Hexham Formation (with Sandgate Seams)
			Four Mile Creek Formation (with Buttai Seams, Donaldson's Seam, Big Ben Seam Tomago Thin Seam)
			Wallis Creek Formation (with Scotch Derry Seam, Rathluba Seams, Morpeth Seam)
	Maitland[4] Group (4,500–6,000′)	Mulbring Subgroup (1,500–3,000′)	
		Branxton Subgroup	Muree Formation
			Belford Formation
			Fenestella Shale
			Elderslie Formation
	Greta Coal[4] Measures (100–300′)		
	Dalwood[4] Group (6,000′)		Farley Formation
			Rutherford Formation
			Allandale Formation
			Lochinvar Formation

[1] Major stratigraphic classification after Booker (1960).
[2] Subdivided by Hanlon, *et alii* (1953).
[3] Subdivided by R. A. Britten (N.S.W. Joint Coal Board) and P. J. Mackenzie (The Broken Hill Pty. Co. Ltd.).
[4] Subdivided by Booker (1960).
[5] Subdivided by J. B. Robinson (N.S.W. Joint Coal Board).

Hunter Region; the Belford Formation (1,500 feet), which is less arenaceous than the Elderslie unit, but otherwise similar in lithology; and the Muree Formation, a thin, but persistent horizon of glacial materials, ranging from tillites to clay-shales. The Mulbring Subgroup is represented by 1,500–3,000 feet of mainly soft argillaceous sediments which, in the lower levels, contain sparse glacial erratics.

(*d*) *Tomago Coal Measures*

Contemporary tectonic activity greatly influenced the sedimentation patterns of the Tomago Group in the Lower Hunter region. Maintenance of shallow-water deltaic conditions along the eastern flank of the rising Lochinvar structure is reflected in the accumulation of 800–1,200 feet of coals and thinly-bedded silt/clay sediments, containing arenaceous channel deposits. Contemporary deeper water environments to the east of the Maitland Coalfield (the Dempsey Beds of David, 1907), are represented by a thick (2,000 feet+) succession of carbonaceous sediments containing little coal. A recent subclassification of the Group by J. B. Robinson (private communication) defines three formations. The basal Wallis Creek Formation is characterized by the predominance of silt/clay lithologies over sandstones. The succeeding Four Mile Creek Formation is distinctly more arenaceous, but like the Wallis Creek unit, contains a number of important coal horizons. The Hexham Formation consists mainly of argillaceous and silty sediments and, except for the two thin Sandgate Seams near the top, lacks coal deposits of economic significance.

(*e*) *Newcastle Coal Measures*

The Newcastle Coal Measures outcropping in the Newcastle-Lake Macquarie region comprise 1,500 feet or more of thick lacustrine conglo-

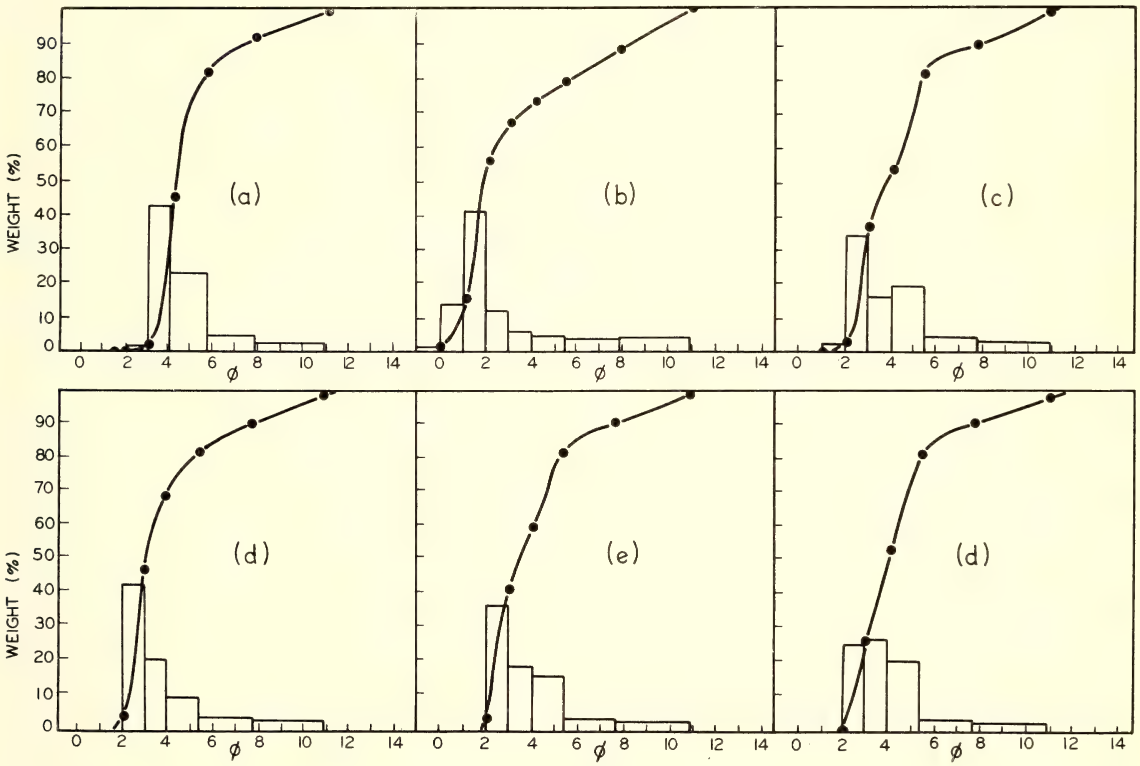

Fig. 3

Cumulative curves and frequency histograms for the particle-size distributions of some Permian arenites.
(*a*) Quartzose arenite, Maitland Group, Cessnock, N.S.W.
(*b*) Lithic arenite, Tomago Coal Measures, Thornton, N.S.W.
(*c*) Lithic arenite, Tomago Coal Measures, Thornton, N.S.W.
(*d*) Lithic arenite, Newcastle Coal Measures, Wallsend, N.S.W.
(*e*) Lithic arenite, Newcastle Coal Measures, Waratah, N.S.W.
(*f*) Lithic arenite, Newcastle Coal Measures, Waratah, N.S.W.

2nd (d) should be (f)

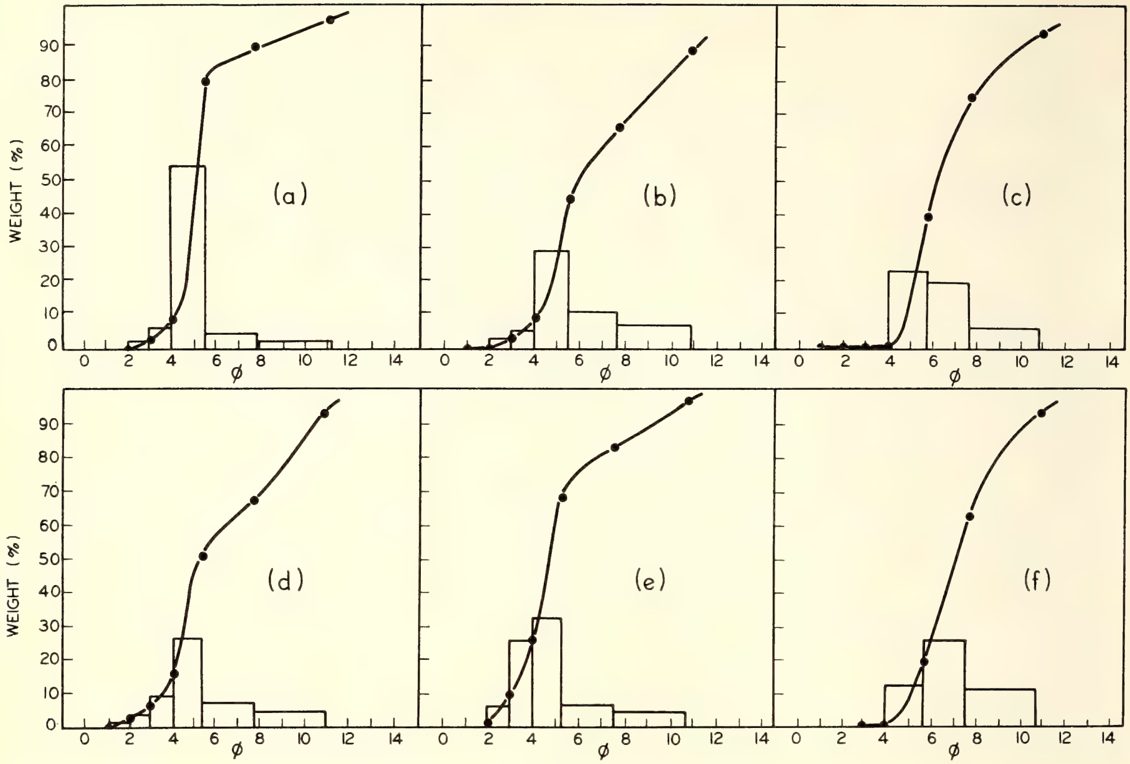

FIG. 4

Cumulative curves and frequency histograms for the particle-size distributions of some Permian silt rocks.
(*a*) Silt-shale, Newcastle Coal Measures, Waratah, N.S.W.
(*b*) Clayey siltstone, Tomago Coal Measures, E. Maitland, N.S.W.
(*c*) Clayey silt-shale, Newcastle Coal Measures, Warner's Bay, N.S.W.
(*d*) Interlaminated sandy, clayey siltstone/silty clay-shale, Tomago Coal Measures, E. Maitland, N.S.W.
(*e*) Interlaminated clayey, sandy siltstone/silty clay-shale, Tomago Coal Measures, Thornton, N.S.W.
(*f*) Interlaminated clayey siltstone/silty clay-shale, Newcastle Coal Measures, Wallsend, N.S.W.

merates and arenites, interbedded with minor deposits of finer silty and argillaceous sediments, and associated with abundant coal seams and tuff accumulations. R. A. Britten (New South Wales Joint Coal Board) and P. J. Mackenzie (The Broken Hill Pty. Co. Ltd.) have suggested a stratigraphic subdivision of the Group, based on " coal seam " and composite " inter-seam " formations (Table 1) to accommodate the inherent complexities of the succession (J. B. Robinson, New South Wales Joint Coal Board, private comm.). Four major Subgroups are defined above the distinctive basal Waratah Sandstone unit—viz. Lambton (bottom), Cardiff, Boolaroo and Moon Island Beach (top). The non-coal lithologies of the Lambton Subgroup are mainly arenaceous and argillaceous. Conglomerates are of minor importance. Tuffs are not common but may form useful stratigraphic marker units (e.g. Nobby's Tuff Member). The Cardiff Subgroup is characterized by abundant developments of thick lenticular fanglomerates interbedded with sequences of delta arenite. Tuff deposits are common, but are usually found in the coal seam sections. The Boolaroo Subgroup represents a period of poor coal development. The thin Hartley Hill and Pilot Seams are interbedded with abundant vitric tuff and clayey arenites. Thick conglomerates are developed locally. The Moon Island Beach Subgroup is lithologically similar to the Cardiff unit, massive conglomerates, tuffs and coals constituting a high proportion of the sequence. The rudite units are generally lenticular and restricted in lateral extent, but some of the thicker deposits (e.g. Teralba Conglomerate Member) may be persistent.

Procedures in Examination of Materials

Some 130 samples, representing full ranges of Tomago and Newcastle Coal Measures lithologies

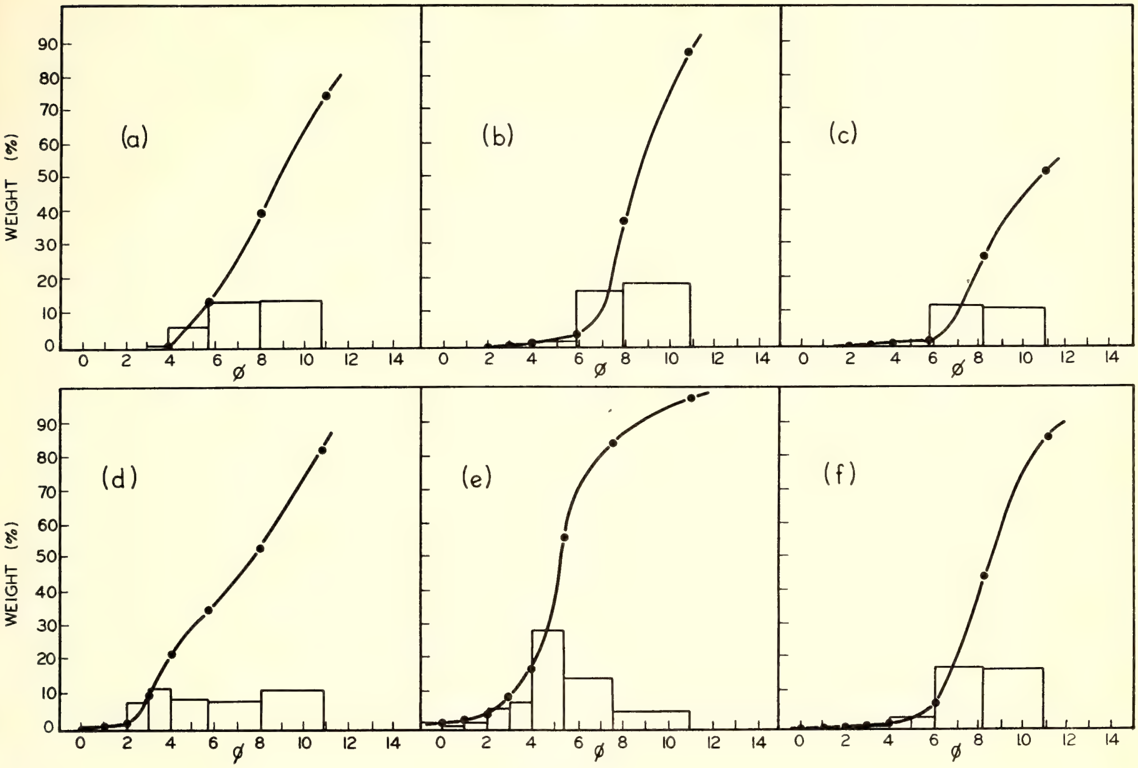

FIG. 5

Cumulative curves and frequency histograms for the particle-size distributions of some Permian claystones and tuffs.
(*a*) Silty clay-shale, Newcastle Coal Measures, Warner's Bay, N.S.W.
(*b*) Silty claystone, Newcastle Coal Measures, Swansea, N.S.W.
(*c*) Silty claystone, Maitland Group, Kurri-Kurri, N.S.W.
(*d*) Sandy, silty claystone, Dalwood Group, Cessnock, N.S.W.
(*e*) Altered vitric-tuff, Newcastle Coal Measures, Swansea, N.S.W.
(*f*) Altered vitric tuff, Newcastle Coal Measures, Swansea, N.S.W.

and a more limited selection of Maitland and Dalwood Group materials, have been examined. Basic textural and mineralogical data have been derived from studies of hand specimens and thin sections supplemented by complete grainsize distribution analyses of all samples and detailed X-ray, differential thermal analysis, chemical, cation exchange, and electron microscopic investigations of their clay-size matrix fractions. Estimates of mineralogical modes for representative sandstone and siltstone types have been made on the basis of counts per 200 to 300 points, in linear microscope traverses across thin sections.

Fifty to sixty gram samples were used for particle size analysis. The materials were easily disaggregated by soaking in dilute (0·1%) Calgon solution and gentle crushing. Dispersion was subsequently effected by stirring for about five minutes in a high-speed mixer. The resulting suspension was passed through a 200 mesh (B.S.S.) sieve, collected in a one litre measuring cylinder and set aside for more detailed analysis. Material retained on the sieve was dried, weighed and passed through a sieve stack containing units of 2 mm., 1 mm., 0·5 mm., 0·25 mm. and 0·125 mm. opening size to ascertain the weight percentages (on an oven dry basis) of the Wentworth "very coarse sand", "coarse sand", "medium sand" and "fine sand" grades respectively (Wentworth, 1922). From the residual suspension containing the minus 200 mesh material, two points (at about 20 microns and four microns) on the particle size distribution curve were determined using the hydrometer method of Day (1950). Finally, the percentage of particles finer than 0·5 micron was estimated on the basis of pipette samples taken from the suspension during settling under controlled conditions.

For purposes of discussion, the size distribution data are presented as cumulative

percentage curve and frequency histograms (Figs 3–5). The system of lithological nomenclature adopted is based on the Wentworth definitions for sand (>1/16 mm.), silt (<1/16 >1/256 mm.) and clay (<1/256 mm.). The scheme is essentially similar to that of Trefethan (1950), but, in providing for a more detailed subdivision of the transition categories, has the added advantage of emphasizing the relative importances of the subdominant size grades. Separate plots of data for "uniform" and "interlaminated" types of Tomago and Newcastle sediments (Fig. 2 (*c*)–(*f*)) are made to facilitate textural comparisons. The cumulative curves and frequency polygons of Figures 2–4 illustrate graphically some important features of the various textures.

Minus 2 micron fractions required for clay mineral analysis were obtained by settling and siphon extraction methods from the abovementioned suspension of minus 200 mesh material. A Philips PW1010 X-ray generator and wide-range goniometer were used in the X-ray diffraction analysis of these fractions. Glass-mounted flake aggregates were used to study the basal diffraction characteristics of the layer-silicate components under air-dried, glycolated and heat-treated conditions. The general diffraction patterns were obtained from random-aggregate specimens, packed in aluminium goniometer cells. Differential thermal curves for the minus two micron fractions were derived using apparatus developed by Carthew and Cole (1953). The micro method described by Mackenzie (1951) was utilized for the determination of cation exchange capacities of both whole sample and clay fraction materials. Morphological studies of the submicroscopic constituents of the matrix fractions were carried out using Siemens electron microscope units. Shadowing techniques were used in most specimen preparations.

(*a*) *Petrography*

(i) *Rudites*

Rudites of the Newcastle Group conform essentially to a single lithological type, viz a fine to medium-grained lithic material, occurring as thick discontinuous lensoid masses, interbedded with other coarsely arenaceous units. Rock structure is typically anisotropic, bedding being clearly defined by sequential variations in grain size, and interbedding of fluvial sand lenses.

The Merewether Conglomerate Member (Kotara Formation) which is well exposed in the gravel quarries at Merewether, three miles south from Newcastle, has been examined in detail. The rock is textually heterogeneous. Bands containing pebbles up to 100 mm. in diameter are abundantly developed through the main aggregate of 10 mm. average grain-size. Most of the constituent fragments are moderately well-rounded. Voids created by the open contact packing of the coarse detritus are filled with sand-size material, and the whole is bonded by a relatively pure cement of secondary clay mineral. The rock is heavily stained by iron oxide throughout the exposed pit section.

Volcanic rock fragments constitute 90% or more of the pebble suites. The majority are fine-grained or divitrified glassy acid types (dacites, rhyolites), which have been tentatively identified, using staining techniques (Bailey and Stevens, 1960). Some types are transected by numerous thin veins of quartz associated with minor chalcedony, white mica and, less frequently, chlorite. Small spherulites and larger irregular segregations of silica minerals may be associated with the veins. Chalcedonic spherules exhibit typical radiating fibrous textures; the quartz patches form inter-locking granular mosaics. Many of the quartz-aggregate grains appear to be derivatives of these quartzose volcanic rocks; others may be derived from granitic and metamorphic sources. Phenocrysts of embayed quartz and prismatic feldspar are not commonly observed, but pyroclastic shards and crystal fragments may be abundant in some rock types. Andesitic and basaltic varieties are rare in the pebble suites.

The inter-pebble sand-size constituents are also predominantly lithic. Accessory types include subrounded quartz, angular plagioclase feldspar and rare flakes of leached muscovite.

Detrital clays appear to be absent from the matrix. In most cases, the interstices are filled with mosaic aggregates of pure, finely vermicular kaolinite. The texture is typically authigenic, but there is no evidence (e.g. replacements of pebble and sand fragments) to confirm such an origin. Patchy developments of montmorillonite in some samples are probably related to a phase of epigenetic mineralization, which has produced changes in and adjacent to principal joint sets, traversing the rock unit. The montmorillonite occurs in the conglomerate as irregular colloform masses and veins of fine, ragged flakes, penetrating along grain margins and producing random replacements of both detrital and primary cementitious constituents.

(ii) *Arenites*

Argillaceous arenites are widely distributed both laterally and vertically throughout the Lower Hunter Permian succession. Three principal types are recognized—viz. fine-grained quartz-feldspar sandstones forming laterally persistent sequences in the Dalwood and Maitland Groups; soft argillaceous lithic arenites constituting the abundant fluvial deposits of the Tomago and Newcastle Coal Measures; and the tough even-grained lithic sandstones of the Newcastle Group, typified by the Waratah Sandstone.

The *quartz-feldspar sandstones*, constituting the basal units of the Farley Formation (Dalwood Group) and Elderslie Formation (Maitland Group) in the Maitland-Cessnock region, are light grey to buff-coloured, fine-grained, massive, compact rocks containing sparsely disseminated coarse sand grains and granules up to 3 mm. in diameter.

The latter (Cessnock Sandstone) consists of closely packed, angular to subrounded fragments of quartz (up to 60%), with associated minor amounts of feldspar rock detritus, sand-size mica flakes, and carbonized plant debris, embedded in a matrix of fine white clay mica (Pl. 1(*a*)). Modal analysis (Table 2, spec. 133) indicates that the rock fragment and feldspar accessories are represented in approximately equal abundance.

Grain shape varies from equant to elongate —sphericities as low as 0·45 on the Rittenhouse scale (Rittenhouse, 1943) have been recorded. The outlines of quartz grains are frequently modified through pressure solution and reprecipitation processes. Sutural contacts so developed frequently entrap matrix clay materials. Indications of original grain outlines are rare. Thus, it is usually difficult to assess the extent of the silica outgrowths. The quartz grains contain only limited quantities of mineral inclusions (especially zircon, muscovite and tourmaline), but fluid inclusions forming fine trails, or occasional larger individual blebs, may be abundant.

Sand-size feldspar components include moderately well-rounded, turbid grains, and fresh, multiply-twinned, prismatic cleavage fragments of sodic plagioclase (albite-oligoclase). Potassic types are represented by rare abraded grains of microcline, showing characteristic "grid" twinning.

The rock fragment suites contain predominant massive and banded, glassy or fine-grained acid volcanic varieties. Chloritized basic rocks and quartz-mica sedimentary materials are present in minor proportions.

The constituent biotite flakes are invariably leached and oxidized and may be partially replaced by fine-grained secondary hydrous micas. Muscovites, too, are usually leached and altered to aggregates of wispy clay. Extensive compactional distortion of the original flakes may be evident in thin section. In some instances, larger flakes may be completely macerated by crushing between adjacent grains of quartz, etc.

Illitic mica and partially ordered 70 : 30 to 60 : 40 mixed-layer mica-montmorillonite predominate over kaolinite in the matrix suites of the quartzose arenites (Table 2). Quartz is a consistent though minor accessory constituent.

TABLE 2

Modal Analyses for Typical Arenite and Coarse Siltstone Lithologies from the Permian of the Lower Hunter River Valley

							Matrix						
								Composition in parts per ten[1]					
Spec. No.	Rock Fragments	Quartz	Feldspar	Mica	$FeCO_3$ Fe_2O_3	Miscell.	%	Kaolinite	Mica	Mica-mont.	Chlorite	Quartz	$FeCO_3$ Fe_2O_3
077	52·7	17·0	8·1	2·5	2·0	0·0	17·7	3·5	0·5	4·5	0·5	1·5	Tr.
099	45·9	17·1	7·2	0·0	6·0	0·0	23·8	3	0·5	4	Tr.	2	0·5
056	56·1	9·7	7·0	0·7	2·2	0·0	24·3	3	1	4	—	1·5	1
063	56·1	14·4	4·8	1·0	3·1	0·0	20·8	3	—	5·5	—	1·5	Tr.
186	64·9	9·8	3·1	1·7	7·1	0·0	13·4	3·5	1	3	—	2·5	Tr.
133	11·1	59·4	13·2	1·7	0·7	0·0	14·0	2·5	0·5	4	—	3	—

[1] Matrix composition estimated from X-ray, cation exchange and chemical data.

The average *fluvial sandstone* is a friable, fine- to medium-grained material, similar in texture and mineralogy to the argillaceous arenites from the Singleton Coal Measures, described by Booker, Bursill and McElroy (1953). The rock type consists essentially of subangular, to moderately well-rounded fragments of rock, quartz, feldspar and mica, embedded in a matrix/cement of fine-grained clay mica and vermicular kaolinite. Rock fragments predominate in the clastic fractions and in the coarsest sediments may be present almost to the complete exclusion of quartz and feldspar. In the finer rock types the ratio rock fragments : quartz+feldspar is of the order of 3 or 4 : 1.

Volcanic rock types predominate in the lithic suites of the fluvial arenites. Quartzophyric and feldsparophyric dacites, banded and spherulitic rhyolites and altered micaceous tuffs are generally represented, and are associated with minor quantities of granite, granophyre greywacke and quartz/feldspar/mica hornfels detritus. Many of the quartz detritals are evidently volcanic derivatives, having smooth, rounded and often deeply embayed outlines (Pl. 1(*b*)), similar in form to the quartz phenocrysts of the lithic constituents. Other more angular, inclusion-riddled fragments, which commonly show evidence of mechanical strain, are comparable with the quartzes of the granitic fragments.

Plagioclase feldspars predominate over potassic types (almost to the exclusion of the latter). Two general conditions of the plagioclase are recognized, viz. fresh, unabraded prismatic cleavage fragments, showing well-developed multiple twinning; and moderately rounded kaolinized and sericitized individuals.

Coarse mica flakes are common minor constituents of the soft lithic sandstones, which do not exceed a maximum of about 5% concentration. Marked decrease in double refraction and bloating of the crystallites in a direction perpendicular to the basal cleavage, indicates progressive degradation and hydration of the materials *in situ* (Pl. 1(*c*)). Ultimate breakdown of the wispy hydrous mica products to kaolinite is frequently evident (Pl. 1(*d*)).

Tuffaceous variants of the lithic arenites occur in the upper levels of the Catherine Hill Bay Formation (Moon Island Beach Subgroup) and in the Triassic Wallarah Volcanic Member overlying the Wallarah Seam. These materials, which are associated with the vitric ash sequences, either as thin interbeds or as thicker adjacent units, typically contain abundant broken, angular, often wedge-shaped splinters of quartz and feldspar, in association with moderately well-rounded lithic detritus, quartz, etc.

Kaolinite and partially-ordered mixed-layer mica-montmorillonites varying widely in relative abundance (ratio 0·5 to 2) are the chief constituents of the matrix/cements of the soft lithic arenites. Quartz is a consistent though minor (<5%) accessory of the minus two micron fractions.

Secondary carbonate replacements of the clay mineral and other chemically reactive constituents (e.g. feldspar, glassy rock) occur sporadically in the Tomago and Newcastle Group arenites. Booker, Bursill and McElroy (1953) have observed similar features in the Tomago sediments from Singleton-Muswellbrook region. Calcium and iron varieties may be associated in these replacements, which range in scale from small patchy granular developments along grain boundaries, to complete carbonate cements (Pl. 1(*e*)). More intense impregnation is generally restricted to narrow bands or thicker discontinuous lensoid zones in the clay-cemented rock units. Hydrated ferric oxides may also extensively replace the clay mineral and secondary carbonate matrix components, especially in zones of iron enrichment in weathering profiles.

The compact, even-grained arenites of the *Waratah Sandstone* unit and the lower part of the succeeding Lambton Subgroup, are similar in composition to the soft fluvial arenites. The fresh rock is grey-green in colour and exceedingly tough. Weathered materials, too, are generally hard and only slightly friable. This characteristic toughness is attributed not only to inherent high textural density, but to developments of thin grain boundary cements of ferrous carbonate (Pl. 1(*f*)).

Tight packing of the constituent rock, quartz and feldspar is evident in thin section (Pl. 1(*f*)). Although often highly deformed by squeezing between the compacted fragments, the larger flakes of mica and carbonized plant material may retain preferred orientation roughly parallel to the bedding direction in the aggregate.

Chlorite, as small mossy green aggregates, is a distinctive minor (<5%) detrital constituent of the Waratah Sandstone (Table 2, spec. 077). Other heavy minerals, including zircon, ilmenite (largely replaced by anatase and hydrous ferric oxides), tourmaline, rutile, apatite, chromite and picotite, are also important accessory constituents. Most commonly these are evenly disseminated through the rock

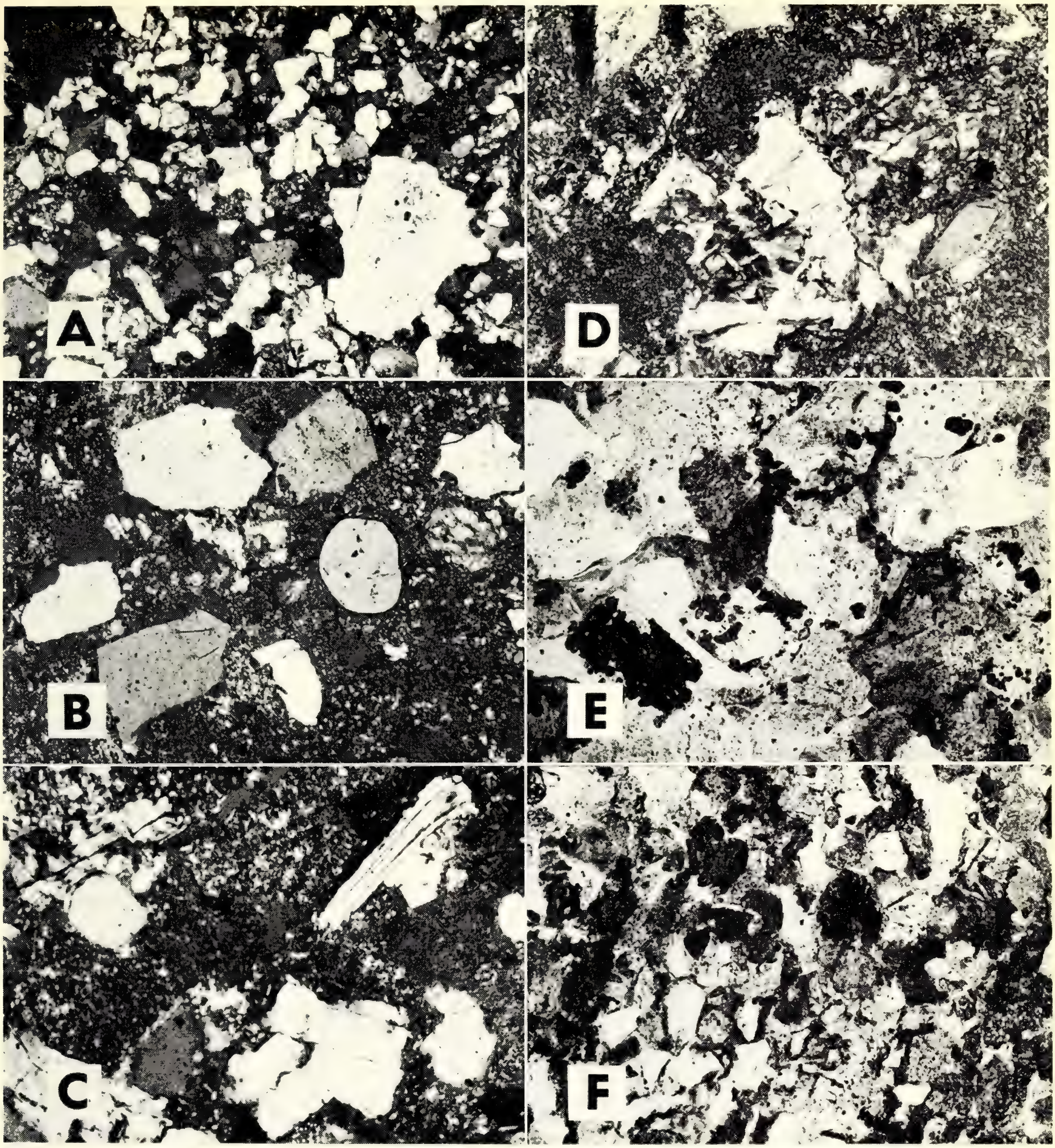

PLATE 1

(*a*) Quartzose sandstone from the Maitland Group (HVC132), showing its closely packed texture. Quartz is the dominant sand-size component ; rock fragments and plagioclase feldspar in subequal proportions are the chief accessories. The sparse matrix consists mainly of kaolinite and degraded mica—crossed nicols—X36.

(*b*) Fluvial lithic arenite from the Tomago Coal Measures (HVM072), showing the variety of shapes exhibited by the quartz constituents—crossed nicols—X36.

(*c*) Micas from a Newcastle arenite (HVN118), showing effects of intrastratal degradation. Muscovite flake at lower left is virtually unaltered, while the others are leached and bloated. Flake at lower right is partially replaced by vermicular kaolinite—crossed nicols—X58.

(*d*) Degraded mica (muscovite ?) flake from a Tomago lithic arenite. Thin remnant layers of highly birefringent material are interleaved with the leached and hydrated mass at left. On the right the flake is replaced by aggregates of weakly birefringent kaolinite—crossed nicols—X143.

(*e*) Secondary iron carbonate replacements in a Tomago arenite (HVM194). The carbonate (very high relief) occurs interstitially, and as replacements of the more susceptible clastic units. The feldspar prism at the lower left is almost completely pseudomorphed—plain light—X22.

(*f*) Waratah Sandstone (HVN076), showing the typical close-packed texture, with the clastics clearly outlined by thin surface layers of finely granular siderite—plain light—X58.

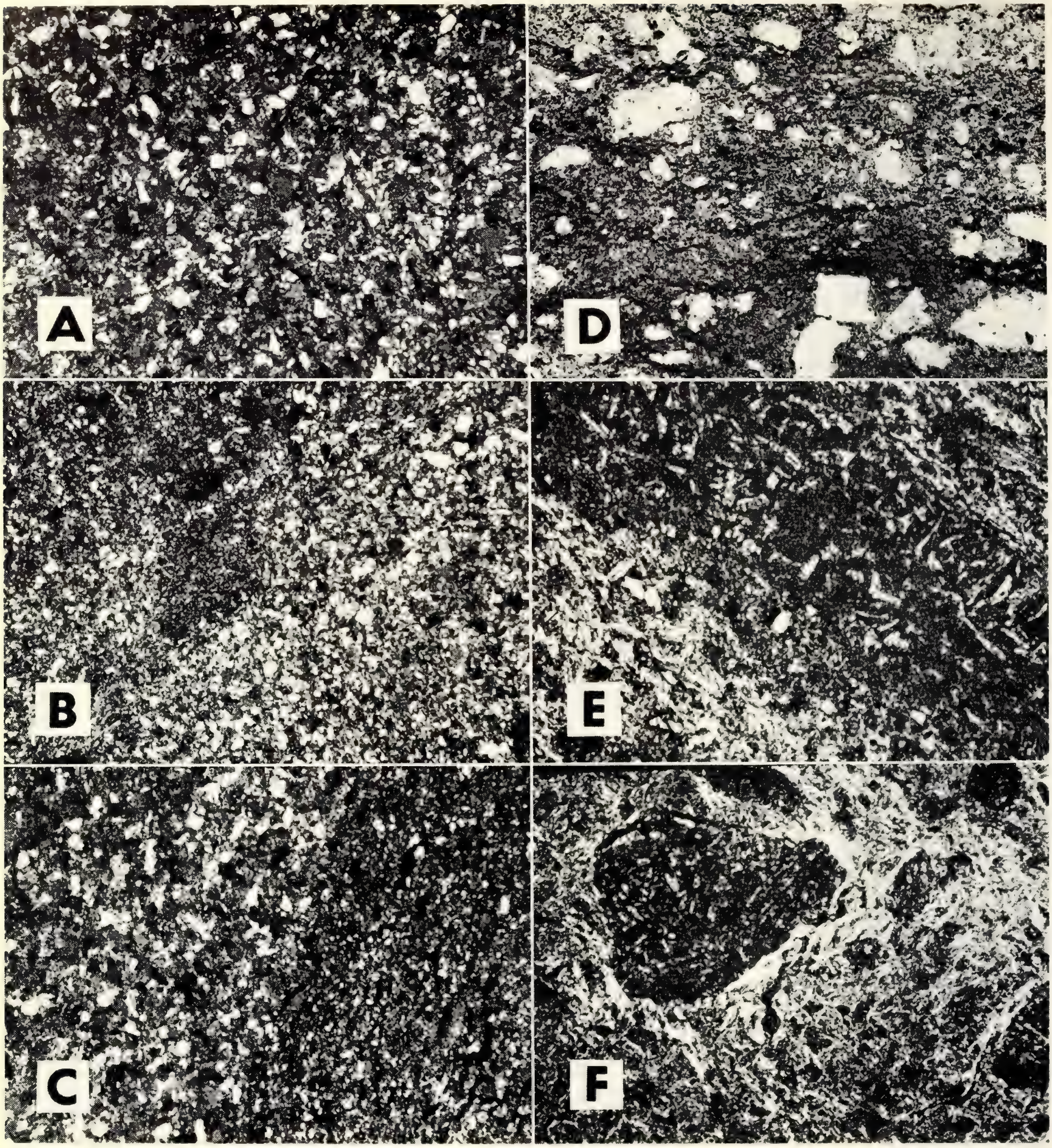

PLATE 2

(*a*) Tomago clayey siltstone (HVM049) consisting of fine to coarse silt-size particles dispersed uniformly :n an abundant clay matrix—crossed nicols—X22.

(*b*) Partially reworked banded texture of a Tomago lutite (HVM052), possibly representing a stage in the development of the uniform texture shown in (*a*)—crossed nicols—X22.

(*c*) Interlaminated siltstone-claystone from the Tomago Coal Measures (HVM067)—crossed nicols—X22.

(*d*) Tuffaceous claystone (HVM189) from the Tomago Coal Measures. Angular fragments of rock, quartz, mica and feldspar are embedded in an abundant matrix of fine clay and carbonaceous material. Much of the coarse detritus is probably of pyroclastic origin—plain light—X57.

(*e*) Vitroclastic texture of the Wallarah tuff (HVN116) from Swansea. Sparse quartz grains occur through the aggregate which is composed predominantly of montmorillonite. Silica may be present in significant amounts in the fine matrix material—crossed nicols—X57.

(*f*) Lithic tuff (HVN105) from the Mount Hutton Formation of the Newcastle Coal Measures. The fragments of vitric tuff are embedded in a matrix of ragged montmorillonite clay particles—crossed nicols—X29.

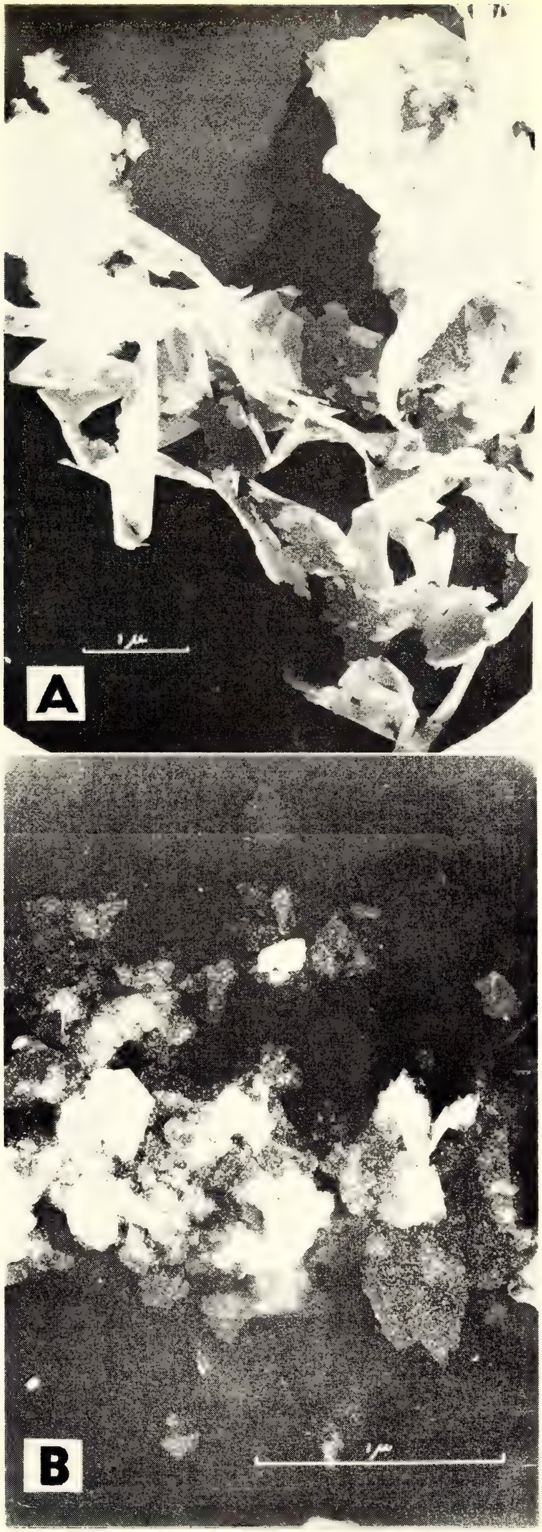

PLATE 3

(*a*) Electron micrograph of a bentonitic clay from the Newcastle Coal Measures, showing filmy, sheet-like crystals of aluminous montmorillonite. Most units are exceedingly thin and flexible and have resisted disintegration during mechanical dispersion.

(*b*) Electron micrograph of bentonitic clay from a thin tuff band in the Scotch Derry Seam (Tomago Coal Measures), showing the fine particle-sizes of the constituent minerals. Platey montmorillonite anhedra contrast strongly with the associated thicker, hexagonal kaolinite units.

aggregate; more rarely they may be concentrated in thin segregation "streaks" through the mass. From "hydraulic equivalence" considerations (Rubey, 1933; Rittenhouse, 1943) high concentrations of heavy minerals are to be expected in fine-grained arenites. However, their segregation from the lighter constituents, in the present instance, seems to imply that the deposits have been subjected to some degree of post-depositional reworking. Such a concept would certainly accord with the well-graded particle-size characteristics of the Waratah arenites.

(iii) *Lutites*

Siltstones and silt-shales are the most common lithologies of the Tomago and Newcastle Coal Measures and possibly of the Permian succession generally.

Significant deposits of relatively pure silt rocks appear to be limited in occurrence to the thick arenite sequences of the stratigraphic successions. Materials containing less than 20% total clay and sand occur in the Newcastle Coal Measures as textural variants of the massive Waratah Sandstone. The matrix of this silt rock typically constitutes about 10% of the total aggregate, while fine sand may be present in concentrations of 5 to 10%. Fresh materials are grey to blue-grey in colour, very compact and hard. Textures are usually massive, but the inclusion of richly carbonaceous bands may frequently impart distinct fissility to the rock.

The mineralogy of the Waratah silts parallels that of the associated arenite lithologies (Table 2, compare 077 and 099). Tightly packed, subangular to subrounded fragments of rock, quartz and feldspar are associated with minor quantities of detrital muscovite, biotite and chlorite in a finely vermicular clay matrix/cement. The massive rock types contain only sparse, disseminated plant detritus. Shaley equivalents contain higher proportions, usually concentrated in discrete bands.

Silt variants, containing as little as 8% matrix clay, are also associated with the marine Cessnock Sandstone.

In the more prevalent lutaceous delta facies, relatively pure silt rocks are represented as lithological variants of channel sand sequences, or more commonly, as thin stringers and laminae in thinly-banded clay/silt materials. The textural heterogeneity of the banded rocks is very evident in hand specimen. Layers of light-coloured massive siltstone up to 2 cm. thick contrast strongly with the carbon-pigmented and strongly laminated clay-rich horizons. Fresh materials are soft to moderately hard, friability being directly related to the proportion of silt layers present. The sharply defined bedding planes are usually undulose and disturbed. Interpenetration contacts between adjacent and coarse elements reflect turbulent conditions of deposition for the silt materials.

The general textural and compositional characteristics of these silt layers imply genetic interrelationships with the arenaceous sediments of the fluvial channel units which are interbedded with the banded rocks. The typical aggregate is composed of fine-grained lithic fragments, quartz, feldspar and leached mica, embedded in a matrix of recrystallized clay mica and secondary kaolinite. The materials are moderately well-packed and particle sizes seldom exceed a maximum of 0·1 mm.

Extensive sequences of the banded silt-clay rocks may include thick persistent interbeds of massive lutite materials, which are moderately carbonaceous, and usually contain high proportions of silt and fine sand. Plate 2(*a*) illustrates the texture, in which an abundant fine sand-silt fraction of quartz, feldspar, mica and macerated plant detritus is dispersed in a matrix of degraded clay mica. The matrix may constitute between 20 and 40% of the rock. The general physical attributes of the massive rocks are clearly intermediate between those of the purer silts and clays, which suggests that they may in fact represent homogenized products of banded silt-clay rocks (Pl. 2(*c*)). This inference is certainly substantiated by occurrences of partially reworked disrupted banding (Pl. 2(*b*)) in many of the uniform clayey silt units.

Permian *claystones and clay-shales* contain high proportions (>70%) of clay particles, but none examined contain the minimum quantity (>80%) requisite for classification as a "pure" claystone. Silt is the chief contaminant. Sand-size components seldom exceed 10% concentration.

Four distinct claystone types have been identified in the studied stratigraphic sections.

Carbonaceous claystones and clay-shales are most commonly developed as the floor and roof rocks of the coal seams in the Tomago and Newcastle Groups. Even textures, fineness of grain and high carbon contents reflect conditions of stable quiescent deposition which ultimately contributed to the accumulation of the coal materials.

Colour and texture of these claystones are governed by the abundance and degree of comminution of the carbonaceous components.

Highly carbonaceous types are dark grey or brown in colour with strong fissility induced by planar concentrations of coarse leafy detritus. Sediments containing only disseminated fine carbon particles are lighter in colour and lack any pronounced bedding fissility.

Non-clay and non-organic clastics are of minor importance. Fine quartz particles up to 0·05 mm. in diameter, and partially leached flakes of muscovite and biotite associated with particles of volcanic and sedimentary rock, rarely constitute more than 5% of the aggregate.

The principal matrix components of the carbonaceous claystones are invariably kaolinite, and randomly interstratified mica-montmorillonite in varying relative proportions. (Tables 2 and 3, specs. 108, 090).

Massive, medium to dark grey *silty claystones* of marine origin (Maitland Group) are exposed in the open cut working of the Hunter Valley Stoneware Pipe Co. at Kurri Kurri. The material is extremely plastic when wet and shrinks markedly on drying.

In thin section the rock appears as a uniform mass of very fine shred-like clay crystals, enclosing rare interspersed silt-size quartz and feldspar particles. Patchy ferric oxide staining is related to weathering in zones adjacent to shrinkage fractures. Preferred orientation of the flaky elements, which is lacking in the fresh rock material, may be developed in these narrow weathered zones, as a result of recrystallization.

Montmorillonite is the dominant individual mineral constituent (Table 3, spec. 130), but kaolinite and quartz in approximately equal proportions together constitute more than half of the aggregate. The minus two micron clay fraction of the sediment is enriched in montmorillonite (60%). Kaolinite (30%) is an important accessory, while quartz is represented in minor quantities only ($<5\%$).

Ferruginous silty claystones of Dalwood age from the Forest Reserve pit of Cessnock Potteries Ltd. are soft to moderately hard, grey or pink, fine-grained massive rocks. Pronounced grittiness is due to the inclusion of quantities of fine sand and silt in the clay. Patchy red colouration results from the partial replacement of the clay matrix by secondary hematite/goethite. Nodular clay ironstone is the ultimate replacement product in some zones.

The iron oxide-free sediment consists essentially of fine sand to coarse silt-size fragments of rock, quartz, feldspar and mica, dispersed through an abundant matrix of clay minerals and very fine quartz silt. Rhyolitic and dacitic volcanic fragments comprise the bulk of the rock detritus. Granitic, granophyric, pelitic metasedimentary and quartzose fragments are also represented as accessory constituents of the suite.

The detrital quartz grains are mainly "metamorphic" types, crowded with dusty inclusions, trails of fine fluid inclusions and occasionally, identifiable crystalline inclusions (especially muscovite and tourmaline). The strained and fractured condition of these quartz crystals readily distinguishes them from "volcanic" derivatives which are typically unstrained and inclusion-free.

Grains of untwinned, slightly kaolinized perthitic potash feldspar are much less abundant than the plagioclase (oligoclase) types, which occur as fresh, twinned anhedra or prismatic cleavage fragments.

The detrital mica group includes muscovite and biotite, showing evidence of severe leaching and hydration (*in situ*).

Sparse fragments of finely macerated plant material are evenly disseminated through the rock. In some cases where the tissue structures have been preserved, intergrowths of secondary clay mica and vermicular kaolinite fill the open cell voids.

Montmorillonite and kaolinite in subequal proportions are the principal constituents of the rock matrix, representing up to 50% of the rock aggregate (Table 3, spec. 137). Iron-enriched rock types show varying degrees of replacement of the clay matrix by aggregates of fine blood-red to orange red hematite/goethite platelets.

Tuffaceous claystone is represented in the section of Tomago sediments exposed in the Waterloo Firebrick Co. pit at Thornton. It is pale brown-pink to medium grey-brown, depending upon the organic carbon content. The more richly carbonaceous layers are slightly fissile, but generally the rock is quite massive and breaks with a conchoidal fracture. Sporadic textural heterogeneities in the form of thin bands or lenticles of silt and sand-size clastic particles are evident on close examination. In thin section these fragmentary constituents are revealed as rock, quartz, mica, and feldspar in that order of abundance. Although concentrated in thin zones, the particles are well dispersed in the abundant fine-grained clay matrix (Pl. 2(*d*)).

The coarse clastics are poorly sorted (estimated size-range 0·02 to 0·80 mm.), and of diverse

TABLE 3

Mineralogical Composition of Fine Siltstones, Claystones and Tuffs from the Permian Deposits of the Lower Hunter River Valley

Spec. No.	Rock Type	Parts per ten[1]								%		
		Rock Fragments	Quartz	Feldspar	Kaolinite	Mica	Mixed-layer Mica-mont.	Mont'lite	Chlorite	Ferric[2] Oxide	Pyrite[3]	Carbon[2]
					PERMIAN Newcastle Coal Measures							
118	Clayey Siltstone . .	—	3	Tr	5	—	2	—	—	Tr	—	Tr
095	Clayey Silt-shale . .	—	3	Tr	3	0·5	3	—	—	1·3	—	0·1
090	Carbonaceous Silty Clay-shale . .	—	4	0·5	3·5	0·5	1·5	—	—	Tr	—	0·2
108	Carbonaceous Silty Clay-shale . .	—	2·5	0·5	4	—	3	—	—	Tr	—	3·0
116	Altered Vitric Tuff . .	—	4	—	1	—	—	5	—	Tr	—	0·1
120	Altered Volcanic Breccia . .	4	—	—	2	—	—	4	—	1·0	—	Tr
097	Weathered Interlaminated Clayey Siltstone/Silty Clay-shale . .	—	3	0·5	3	1·5	1·5	—	0·5	Tr	—	Tr
					Tomago Coal Measures							
058	Clayey Sandy Siltstone . .	—	3	0·5	1·5	0·5	5	—	—	0·5	—	1·1
060	Sandy Clayey Siltstone . .	—	2·5	0·5	1·5	0·5	4	—	—	—	—	0·5
180	Interlaminated Clayey Siltstone/Siltstone	—	3	0·5	2	0·5	4	—	—	Tr	—	0·2
197	Clayey Siltstone . .	—	2	0·5	1·5	0·5	—	4·5	—	0·2	—	0·1
195	Interlaminated Clayey Siltstone/Silty-Clay-shale . .	—	3	0·5	2	0·5	—	4	—	—	—	0·5
061	Interlaminated Sandy Clayey Siltstone/Silty Clay-shale . .	—	4	0·5	3	1	2	—	—	—	—	0·5
181	Interlaminated Clayey Siltstone/Silty Clay-shale . .	—	3·5	Tr	2	1	3·5	—	—	Tr	—	0·1
176	Interlaminated Clayey Siltstone/Silty Clay-shale . .	—	3	Tr	2	1	4·5	—	—	Tr	—	0·8
182	Interlaminated Clayey Siltstone/Silty Clay-shale . .	—	4	—	2·5	Tr	3	—	—	—	—	0·1
054	Carbonaceous Clayey Silt-shale (Micaceous) . .	—	2·5	Tr	1·5	1	5	—	—	—	—	1·9
052	Interlaminated Clayey Siltstone/Silty Clay-shale . .	—	3·5	0·5	1	1	—	4·5	—	—	—	0·3
089	Tuffaceous Silty Claystone . .	Sparse Lithic Frags.	3·5	—	2	1	3·5	—	—	—	—	0·3
068	Tuffaceous Clayey Siltstone (Micaceous)	Altered Volcanic Rock	0·5	Tr	5·5	0·5	3·5	—	—	Tr	—	0·8
069	Bentonitic Clay (Pyritic) . .	Altered Pumice	0·5	—	2·5	—	—	7	—	Tr	3·0	0·2
059	Weathered Silty Claystone . .	—	2·5	0·5	1·5	1	4·5	—	—	—	—	0·2
					Maitland and Dalwood Groups							
130	Silty Claystone . .	—	3	Tr	3	—	—	4	—	—	—	Tr
137	Ferruginous Sandy Silty Claystone . .	—	3	0·5	2	—	—	3	—	2·5	—	0·4

[1] Determined by X-ray, cation exchange and chemical analysis.
[2] Determined by chemical analysis.
[3] Determined by heavy mineral analysis.

shapes. Quartz occurs as highly angular fragments, arcuate and wedge-shaped splinters, or even as well-rounded and embayed grains. The rock fragments including sedimentary and metamorphic, as well as acid volcanic varieties, typically show moderate rounding. However, some volcanic fragments may possess highly angular outlines. The larger detrital mica flakes in general show evidence of extensive leaching and hydration.

Clay minerals constitute at least 80–90% of the rock matrix. Hydrous mica and mixed-layer mica-montmorillonites predominate, and are associated with kaolinite in approximately 2 : 1 proportions (Table 3, spec. 189). The remaining 10–20% of the matrix comprises comminuted plant detritus distributed fairly uniformly through the clay aggregate.

The genesis of this rock type is obscure. While some features, especially those related to the nature and distribution of the erratic silt and sand components, would imply a partly pyroclastic origin at least, others would indicate a normal detrital source. Certainly the occurrence of mixed-layer minerals rather than montmorillonite in the clay grades, suggests a closer relationship to the non-volcanic sediments than to the tuffs.

Adjacent to pyritic coal seams the tuffaceous claystones are extensively leached and recrystallized. Mixed-layer micaceous components are largely converted to kaolinite, which may constitute up to 75% of the clay fraction. The original heterogeneous texture of the rock is usually well preserved. The more susceptible constituents (rock fragments, feldspar, mica) are at least partially replaced by aggregates of secondary vermicular kaolinite and finely granular ferrous carbonate. The carbonate is restricted mainly to the coarse-grained bands and is consistently associated with carbonized plant materials. One occurrence of such leached material in the Thornton Fire and Building Brick Co. pit at Thornton (Pl. 2(*d*)) contains numerous small rods and prisms of apatite up to 0·1 mm. in length, concentrated mainly in the coarser-grained laminae. The fresh euhedral and unabraded subhedral condition of the crystals and the inclusion of sparse fluid-filled cavities suggests a primary pyroclastic origin for this constituent.

(iv) *Tuffs*

Tuffs are more prevalent in the Newcastle than in the Tomago Coal Measures successions. Bentonitic deposits of the Tomago Group are typically thin, but are often laterally persistent, especially as bands in coal seams. Similar types of deposits occur in the Newcastle sequence, but are usually associated with other thicker units, which may be of very limited lateral extent.

Soft, waxy or plastic clays largely replace the original components of the coal seam tuff bands. Textural characteristics of the original pyroclastic products are retained to varying degrees in the clay aggregates. The thickest band from the Scotch Derry Seam (Tomago Group) at Thornton retains only a few relict features indicative of original rock character. This clay is light grey to white in colour, often stained yellow by free sulphur from the coal, and flecked with black, due to included carbonaceous material and secondary pyrite crystal aggregates. The dry clay is soft and friable ; when wet it is extremely plastic.

The coarse pyroclasts have been largely replaced by clay aggregates, but some quartz, feldspar and lithic fragments are still identifiable. Relict outlines indicate original particle diameters ranging up to 1 mm. and averaging about 0·5 mm. The grains were evidently angular, ovoid and less frequently, splinter-shaped.

Two principal phases are represented in the secondary clay suites. Dioctahedral montmorillonite, as colourless to pale yellow aggregates of fine ragged crystals, replaces the greater part of the original matrix material and embedded pyroclasts. The subordinate colourless vermicular kaolinite component occurs mainly as pseudomorphs of other coarse clastic units. The constituent clay particles, as a rule, lack preferred orientation, but may show small degrees of aggregate alignment adjacent to, and parallel with, the margins of the replaced fragments. Radial orientation patterns are sometimes developed in clay aggregates, replacing the bubble walls of pumice particles.

Tuffs of the Newcastle Coal Measures are typically more " rock-like " in the unweathered condition. Fresh materials from a thick (30 ft.+) sequence of the Wallarah Tuff Member (subunit of the Munmorah Conglomerate), exposed in the Belmont Stoneware Pipe Quarry at Swansea, are hard, brown to grey-brown clay rocks, somewhat " chert-like " in appearance, and have a distinct waxy lustre. Variations in carbon content accentuate the bedding and reveal developments of small-scale sedimentary structures—especially current bedding. The hardness of the rock possibly reflects a moderate degree of silicification.

A high silica content is certainly indicated by the bulk rock composition (Table 3, spec. 116).

The Wallarah tuff (Pl. 2(*e*)) has a well-developed vitroclastic texture (Williams, Turner and Gilbert, 1954, p. 154). However, much of the original glassy ash and lithic components have been replaced by secondary montmorillonite. Leached mica flakes and splinters of quartz and plagioclase, up to 0·2 mm. in diameter, are the chief accessory constituents of the aggregates. Welding is not apparent. The textures of vesicular pumice fragments are often pseudomorphed by aggregates of radially-disposed clay scales, which replace the bubble walls as sequences of concentric shells. The original textures of most other lithic pyroclasts are recognisable only where clay replacements are incomplete.

Very fine-grained vermicular kaolinite is probably the dominant matrix component. Secondary iron oxides and carbonate are minor accessory constituents, especially in zones adjacent to iron-enriched bedding horizons and joint fissures.

Tuff from the Kotara Formation (Cardiff Subgroup) exposed in Wardley's Clay pit at Hillsborough, is distinctly more lithic. In this section (Pl. 2(*f*)) fragments of vitric tuff and tuffaceous lava are visible in an abundant matrix of montmorillonite and kaolinite clay particles.

Small deposits of coarser lithic ejectamenta occur in the Wallarah Tuff Member at Swansea. In the section exposed in the Belmont Stoneware Pipe Co. pit, the Wallarah Seam rests directly upon a six to eight inch band of volcanic breccia, consisting of lithic and crystal fragments up to 3 cm. in diameter (average 3 mm.), embedded in a massive matrix of extremely plastic montmorillonite/kaolinite clay (Table 3, spec. 120). The material has a streaky pink-white colour due to patchy iron staining. The clastic fraction, which may constitute 70–80% of the aggregate, includes fragments of heavily iron-stained dacitic and rhyolitic rocks with fine-grained or glassy textures; crystal tuffs, containing abundant ill-sorted angular particles of quartz, feldspar and flakes of mica; and tuffs, showing vitroclastic and vesicular textures, pseudomorphed by clay minerals. Coal fragments occur sporadically in the aggregates. Larger quartz and feldspar grains up to 0·2 mm. in diameter are minor constituents only. The quartz pyroclasts have well-rounded and embayed outlines, are commonly fractured, and contain inclusions of ferric oxide. Kaolinized cleavage fragments of albite/oligoclase are the dominant feldspar components. Fresh sanidine crystals may also occur rarely.

(*b*) *Grainsize Distributions*

(i) *Arenites*

Arenites from the Lower Hunter Permian succession are well-sorted to moderately well-sorted sediments. The distributions of quartzose sandstones from the Dalwood and Maitland Groups (Fig. 3(*a*)) typically show small deviations (σ_φ[1]$=1{\cdot}5$–$2{\cdot}0$) about well-defined modes in the fine to very fine sand grades (φ[2]$=2$–4). Lithic arenites of the Tomago and Newcastle Groups are on the average less well-sorted ($\sigma_\varphi=2{\cdot}5$–$3{\cdot}5$). These higher deviations in most cases, are attributable to the inherent bimodality of the distributions for the traction grades of the aggregates. Figure 3 demonstrates the range of textural variation in these coal measures rocks. From the plots it is clear that both open deltaic products of the Waratah Sandstone type ((d)–(*f*)) and the more prevalent channel sand deposits ((*b*), (*c*)) show wide variations in silt content. The extensive "tails" usually developed in the clay range ($\varphi>7$) of the arenite size distributions are not *primary* textural phenomena, but are reflections of the particle-size and dispersion characteristics of the secondary matrix components.

(ii) *Lutites*

The lutites of the Tomago and Newcastle Coal Measures comprise a complete lithological suite linking the arenite and claystone textural extremes. From Fig. 2(*c*), (*e*) it is evident that, within the sandstone/clayey siltstone range, particle-size variations are related primarily to changes in sand content, the ratio silt : clay remaining virtually constant. For Tomago Coal Measures sediments an average ratio of 3 : 1 is indicated; for Newcastle Coal Measures materials the value appears to be higher—about 4 : 1. Analyses of the thinly banded siltstone/claystone sediments plot mainly within the "clayey siltstone" region of the triangular diagram (Fig. 2(*d*), (*f*)). The evident mechanical similarity of the banded rocks and other homogeneous clayey siltstones may well be significant, especially in the light of earlier inferences concerning the origin of the latter type. For coal measures sediments containing less than about 10% sand, the silt : clay ratio decreases progressively towards an observed minimum of

[1] Deviation measure proposed by Inman (1950).

[2] $\varphi=-\log_2 d$ where "d" is particle diameter in millimetres.

approximately 0·25. Corresponding sediments from the marine successions may be even more clay rich.

In general, the grain-size distributions of the silts are negatively skewed about single, prominent modes in the size range $\varphi=4$–6. The size distributions of the claystones are more diverse in character. Poor grading is typical. Principal modes are ill-defined (e.g. Fig. 5(*b*) (*c*)) or virtually lacking (Fig. 5(*a*)). The " sand " mode in Fig. 5(*d*) is due to an admixture of glacial erratic material in the claystone.

(iii) *Tuffs*

Particle-size analyses of tuffs from the upper coal-bearing successions do not reflect primary textural characteristics so much as the morphological conditions of the secondary clay mineral constituents. Electron micrographs of the minus two micron fractions of two montmorillonitic bentonites from Swansea (Pl. 3(*a*)) and Thornton (Pl. 3(*b*)) demonstrate the contrasting natures of the principal mineral components of these materials under normally dispersed conditions. On this basis the marked differences in particle size distribution (Fig. 5(*e*), (*f*)) of the parent clays may be readily appreciated.

Summary and Conclusions

Although largely restricted to a consideration of the Tomago and Newcastle Coal Measures the present study has served to demonstrate the broad compositional uniformity of the Permian sediments of the Lower Hunter region. Petrographic evidence has indicated that at least two major source environments contributed to the development of the wide range of epiclastic lithologies represented in the successions —one predominantly volcanic and unmetamorphosed—the other of deformed granitic and metamorphic character. The closely comparable sedimentary suites of the Tomago and Newcastle Coal Measures are dominated by detrital volcanic components ; those of the associated Dalwood and Maitland (marine) Groups received more or less equal contributions from the volcanic and metamorphic sources.

Contemporaneous volcanic ash deposits, especially abundant in the Newcastle sequence, are largely altered to montmorillonite/kaolinite clays.

Parallelism of textural trends in the Tomago and Newcastle sedimentary suites is confirmed by the grain-size distribution data.

The unique stratigraphic, textural and mineralogical attributes of the Waratah Sandstone unit set it in marked contrast to the fluvial sands of the Tomago and Newcastle sequences. Lateral persistence and lithological uniformity especially suggest development under unusually widespread, active sedimentary conditions—possibly in an open lacustrine environment—providing opportunity for extensive reworking and sorting of the materials.

The genetic interrelationships of the various lutite lithologies are fairly clear. The silt rocks of the Waratah Sandstone are unique. Like their arenite counterparts they are well-sorted and highly consolidated. The more typical deltaic interfluvial deposits include rock types ranging from thinly interlaminated siltstone/claystones, to massive clayey siltstones. Observed field and textural relationships imply a genetic link between these seemingly diverse lithologies. The evidence suggests that the laminated textures, which appear to be fundamental to the interfluvial environments, have been locally reworked to form the massive (but mechanically identical) clayey siltstone units.

Poor sorting in the claystone rock types may be at least partly due to hybridisation. Thus, secondary modal concentrations in the *coarse* grades of some materials are nearly certainly primary detrital features, representing admixtures of flakey detritus (e.g. mica, plant fragments), or even erratic materials of volcanic or glacial origin (e.g. Fig. 5(*d*)). Other features of the distributions, especially those related to the clay grades probably reflect the degrees of dispersion more than the original micellar distribution characteristics of the component minerals and thus lack any real geological significance. The particle-size distributions of the altered tuffs too, are probably functions of dispersion and are virtually unrelated to the original pyroclastic textures of the materials.

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The Geology of Mandurama–Panuara

R. E. Smith

Abstract—Investigation of an area between Mandurama and Panuara, approximately 30 miles south of Orange, New South Wales, has resulted in more detailed knowledge of the stratigraphy and petrology of the Ordovician and Silurian formations as defined by Stevens (1952 and 1954), and Bruce and Langley (1949). There is a lateral facies change in the Angullong Tuff from lavas, tuffs and breccias in the west to a volcanic labile greywacke suite together with subordinate lavas in the east. This confirms the presence of a north-south trending Ordovician volcanic island ridge which passed through the west of the Area associated with the Molong Geanticline as described by Packham (1958). The alteration of the Ordovician formations correlates with the prehnite–pumpellyite metagreywacke facies of Coombs (1960). The graptolite assemblages investigated indicate a Darriwilian age (zones D2–D3) for part of the Ordovician Malongulli Formation, and a Melbournian age for part of the Silurian Panuara Formation.

Introduction

The Area described in this paper lies approximately 30 miles south of Orange between Mandurama and Canowindra, see Fig. 1. The lithologies present in the Area studied represent sedimentation and vulcanism from pre-Middle Ordovician time (as represented by the Walli and Mount Pleasant Andesites) through Middle Ordovician and Upper Ordovician times (represented by the Cliefden Caves Limestone, Malongulli Formation, and the Angullong Tuff). A structural gap exists in the history between the Upper Ordovician Angullong Tuff and the Upper Silurian section of the Panuara Formation.

Zoning of graptolites was obtained by reference to Thomas' paper (1960), " The Zonal Distribution of Australian Graptolites ". Field locations of points of interest are given using the standard Military grid for the Blayney and Canowindra one inch to the mile sheets. The subscripts ' 2 ' and ' 8 ' as shown on the map, Fig. 6, have been omitted in the text for simplicity. The five figure numbers of specimens refer to rock thin sections catalogued in the University of Sydney.

The Ordovician formations, namely, the Angullong Tuff, Malongulli Formation, Mount Pleasant and Walli Andesites, have undergone alteration of a regional extent, presumably due to burial. The mineralogical adjustments are extensive and hence the rocks are said to have undergone a low grade of metamorphism. The original textures of the rocks are usually visible and schistosity is generally absent. The rocks have been deformed by simple concentric folding.

This paper follows the regional investigations of Stevens in his Ph.D. thesis (University of Sydney, 1954), and his papers of 1952 and 1953.

Owing to the scale of the map, Fig. 6, detail of field mapping could not always be included,

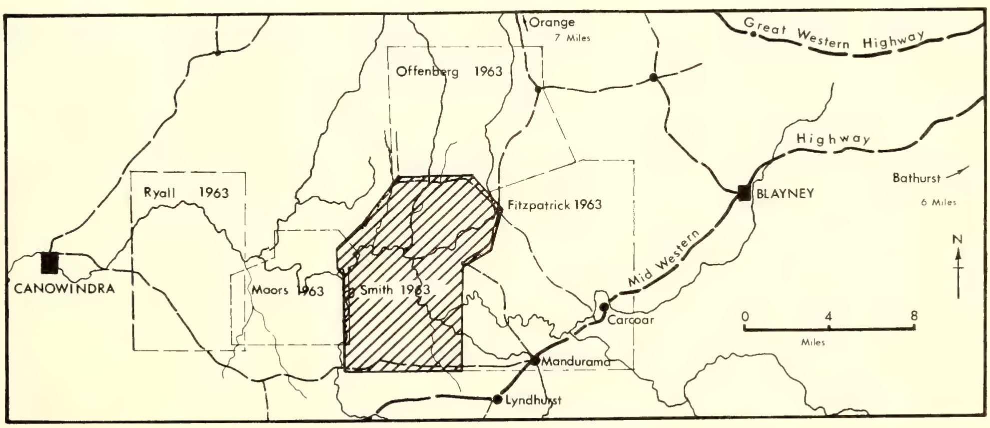


Fig. 1

and interested readers are referred to the original thesis at the University of Sydney, where a detailed map at the scale of one inch = approximately 800 feet is available. The quality of outcrop in the Area is generally good, in places it is excellent, as, for example, along Swallow and Cadiangullong Creeks and the Belubula River. There is an area south of 'Millamolong' Station, where outcrop is poor and the lithology can only be inferred from the soil characteristics, the structure being obscure.

Stratigraphy and Petrology

Walli Andesite

Definition. Stevens (1954): "The Walli Andesite (after Walli, a locality north of Woodstock) is the name given to volcanic rocks which make up the oldest Ordovician formation exposed. The type area lies between Walli and Limestone Creek, and the best outcrops are along the creeks which flow north into the Belubula River . . .". As bedded members are infrequent, the thickness of the formation can only be estimated; however, there appears to be at least 4,000 feet of sequence in the Davy's Creek Anticline. Outside the Area studied, the formation outcrops in a belt five miles wide, extending south to Woodstock, but the base of the formation is not known to outcrop.

The Walli Andesite dips to the north-east on the east limb of the Davy's Creek Anticline, named by Stevens, 1954, and is conformably overlain by the Cliefden Caves Limestone. Good exposures of Walli Andesite are offered

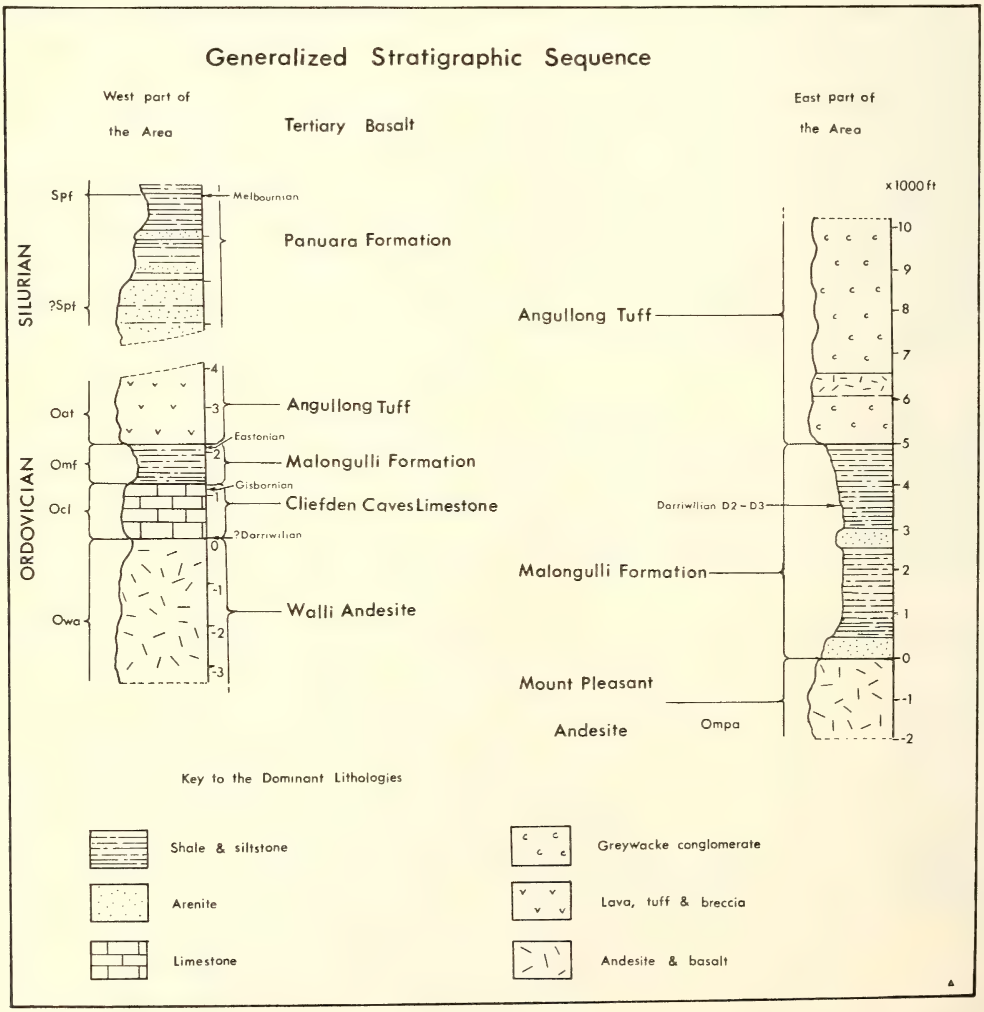


Fig. 2

in the Limestone Creek section, between grid references (880400) and (882430).

The Walli Andesite consists predominantly of porphyritic andesites and fine-grained vesicular basalts, associated with subordinate volcanic breccia and tuff. Excellent pillow lava structures are exposed along Limestone Creek, for example at grid reference (882418) where pillow lava grades downward into non-pillowed amygdaloidal lava. The pillows range from four feet to eight feet in diameter, frequently with subspherical upper surfaces. Adjacent pillows tend to mould upon one another, and are separated by thin dark-green chilled selvages ¼ to ½ inch across. Bands of breccia, usually less than one inch across, may occur between the chilled selvages. Amygdules often show concentric elongation near the margins of pillows, however, other amygdules may show radial elongation.

The basalts are fine-grained hypocrystalline with intersertal to microlitic textures. Phenocrysts are not abundant in the basalts, however, when present they tend to form clusters resulting in glomero-porphyritic textures. The phenocrysts consist of albite, augite, and pseudomorphs after both pyroxene and olivine, in that order of abundance. The olivine is always pseudomorphed, and is only recognised by its euhedral outline. The pyroxene shows various stages of replacement by secondary minerals but in many cases relic augite remains. Growth of the secondary minerals quartz, albite, chlorite, prehnite, epidote, carbonate, and pumpellyite has somewhat modified the textures.

The andesites are porphyritic with large phenocrysts up to 8 mm in length of albite, sometimes in association with phenocrysts of hornblende or augite. The groundmass may be trachytic, having microlites of albite with interstitial chlorite, epidote, granular opaques and sphene ; or may be a felt of albite laths, chlorite, epidote, opaques and sphene. Acicular opaques are widespread accessory minerals in the Walli Andesite.

The lavas and breccias of the Walli Andesite show various stages of low grade metamorphic alteration with the formation of the following authigenic minerals : albite, chlorite, epidote, prehnite, pumpellyite, quartz, carbonate, and sphene. The same minerals occur as amygdule fillings. Such a mineral assemblage indicates a grade of metamorphism similar to the prehnite-pumpellyite-metagreywacke facies of Coombs, (1960).

The widespread occurrence of Cliefden Caves and equivalent limestones overlying the Walli and Cargo Andesites indicated general marine conditions followed the extrusion of the andesites. Limestone at grid reference (875400) lies within Walli Andesite. In addition the frequent occurrence of pillow lavas suggests an underwater environment. On the above evidence, it appears that much of the Walli Andesite was probably extruded under marine conditions. No other indication of environment was obtained.

Mount Pleasant Andesite

The formation was named by Bruce and Langley (1949) after Mount Pleasant, grid reference (008430) where the rocks form a prominent outcrop.

The Mount Pleasant Andesite outcrops in the south-east corner of the Area, and is conformably overlain by cherty shales, siltstones and arenites of the Malongulli Formation, at grid reference (985420). Porphyritic andesites and basalts are interbedded with thin beds of volcanic labile arenite and siltstone. The formation appears to be 1,600 feet or more in thickness at Mandurama Ponds Creek. As both the Walli Andesite and the Mount Pleasant Andesite are the first volcanic formations below the Malongulli Formation, they are considered equivalent formations. The Cliefden Caves Limestone which separates the Malongulli Formation from the Walli Andesite at Limestone Creek is absent from the sequence at Mandurama Ponds Creek.

Although no fossils have been found in this formation, it is known to be pre-Darriwil in age as Darriwilian graptolites have been found in the Malongulli Formation, see location CO.1/40, 41, 42, 43, this paper. Darriwilian graptolites were also found by Stevens (1954) in the Malongulli Formation above the Mount Pleasant Andesite in Mandurama Ponds Creek, at grid reference (990428).

Pillow lavas are exposed in Mandurama Ponds Creek at grid reference (987416), 300 feet below the upper contact of the formation. The largest pillows are 8 feet in diameter, and are separated by a thin silty interpillow matrix varying from ½ to 1 inch in thickness.

The porphyritic basalts have phenocrysts of albite and pale green augite ; the augite being in various stages of replacement by tremolite-actinolite. The groundmass is felty consisting of albite laths, interstitial chlorite, and ragged acicular secondary tremolite-actinolite, with granular epidote, sphene, and opaques.

A representative andesite, slide 23070, has phenocrysts of green-brown primary hornblende in addition to the albite phenocrysts. The groundmass is felsitic, and there is only a trace of opaques.

The thin sections of the Mount Pleasant Andesite show alteration to albite, epidote, tremolite-actinolite, pumpellyite, carbonate, and sphene. The alteration could be due to hydrothermal activity related to an igneous body, such as the Prince of Wales Diorite, or perhaps more probable, be due to low grade metamorphism of a regional nature. If the latter be the case, the Mount Pleasant Andesite can be correlated with the higher zone of Coombs' prehnite-pumpellyite-metagreywacke facies of metamorphism.

Some of the basaltic and andesitic pillow lavas of the Mount Pleasant Andesite may have been sill-like bodies intruded into semiconsolidated marine sediments. An extrusive lava may cause partly intrusive relations with the overlying sediments by ploughing into semiconsolidated muds.

Cliefden Caves Limestone

Definition. Stevens 1954 : " The Cliefden Caves Limestone takes its name from the caves which are situated in the upper part of the formation on the south side of the Belubula River, 10 miles north of Woodstock . . . The formation consists chiefly of light-grey massive limestone ; at some places thinly-bedded fossiliferous limestones are present at the base. The maximum thickness is about 2,000 feet, east of the Cliefden Caves ".

The Cliefden Caves Limestone conformably overlies the Walli Andesite and conformably underlies the Malongulli Formation near Limestone Creek, grid reference (881421), but is absent from the sequence at Mandurama Ponds Creek where the Malongulli Formation conformably overlies the Mount Pleasant Andesite, grid reference (988420).

At Limestone Creek, large brachiopods and corals are common in the bedded limestone which forms the lower member, however, there is a vertical change to massive grey limestone with occasional chert nodules. Fossil fragments do not form a conspicuous part of the massive limestone, but organic remains are sometimes visible in thin section ; one such slide contained part of a bryozoan, slide 23096.

One mile to the north-west of Limestone Creek, at grid reference (875435), the structure is simple and the Cliefden Caves Limestone is seen to be approximately 800 feet in thickness. Just how far the limestone continued eastward from its outcrop at Limestone Creek is not known, as the top of the Walli Andesite-Mount Pleasant Andesite is not exposed between this creek and Mandurama Ponds Creek. However, it is apparent, due to the absence of the Cliefden Caves Limestone at Mandurama Ponds Creek, that the limestone has undergone a facies change.

The cherty shales and siltstones, which form much of the Malongulli Formation at Mandurama Ponds Creek, probably represent deposition in a bathyal environment. The distribution of the Cliefden Caves—and equivalent—Limestones represents part of the paleogeographical neritic environment which was associated with the structural ridge, the Molong Geanticline. The conclusion is that, during Middle Ordovician times, there was a general deepening of the sea eastwards, away from the meridional geanticlinal ridge, the axis of which lay close to the west margin of the Area.

Moors (1963), working in the area immediately to the west of Limestone Creek, states that part of the Cliefden Caves Limestone is definitely Gisbornian in age and may extend down into the Darriwil.

Malongulli Formation

About one-third of the Area shows outcropping Malongulli Formation. This formation forms most of the central portion of the Area. A complete sequence of the Malongulli Formation is exposed along Mandurama Ponds Creek and part of the Belubula River, as is described below. There appears to be a major anticlinal structure in the centre of the Area, causing the formation to show a wide outcrop.

Definition. Stevens 1954 : The Malongulli Formation . . . " is named after the Parish of Malongulli, north of Woodstock. The type area is between Malongulli Trigonometrical Station and the Belubula River near ' Kalimna ' . . . Two distinct facies are present ; a calcareous facies in which most of the sediments are laminated calcareous siltstones or impure limestones (spiculites), and a siltstone-arenite facies, in which the sediments are feldspathic siltstone interbedded with arenites, tuffs and some lava flows.

" The calcareous facies is developed in the type area . . . The siltstone-arenite facies of the Malongulli Formation is developed in a broad arc east, north and south-east of Cliefden Caves. "

The occurrences of the Malongulli Formation described in this paper should, therefore, lie in Stevens' siltstone-arenite facies. It is apparent, however, that this division of the Malongulli Formation into separate facies is a generalization and, in fact, most of this formation in the west and central portions of the Area are transitional between the two facies of Stevens. The Malongulli Formation in the east at Mandurama Ponds Creek can be placed in the siltstone arenite facies.

Mandurama Ponds Creek Section

Between Junction Reefs and the Mandurama—Canowindra Road, beds of the Malongulli Formation outcrop. They strike north-east and dip gently north-west at 25° to 30°. The upper boundary of the formation has been mapped against the overlying Angullong Tuff, grid reference (946462), about a mile north of Junction Reefs. The lowest unit of the Malongulli Formation conformably overlies andesitic lavas and volcanic labile arenites of the Mount Pleasant Andesite at grid reference (988421). Several east-west trending faults outcrop along the Belubula River at Junction Reefs, grid reference (967436), the total displacement of the series of faults has been calculated by Henderson (1953) as being 600 feet, south block down, causing repetition of the ore beds either side of the river. A total thickness of 5,500 feet (corrected for the fault displacement) of Malongulli Formation is exposed in sequence at Mandurama Ponds Creek ; the accuracy of the total thickness is expected to be ± 500 feet.

In this sequence the Malongulli Formation can be divided into three dominant lithologies :

(i) Cherty shales and siltstones, which form 75% of the formation.

(ii) Labile arenites, which form 20% of the formation.

(iii) Andesites, which form 5% of the formation.

(i) The shales and siltstones vary from light-grey to black in colour, and have a conchoidal fracture when fresh. The rocks are well bedded with bedding planes separated at intervals of 2 inches down to less than $\frac{1}{16}$ of an inch. The weathered rock is hard, light-grey to buff and sometimes leached in outcrop. The fresh rock is often pyritic, calcareous, and exceedingly hard to split along bedding planes. The detritus consists of feldspar (mainly plagioclase), quartz (usually less than 25% of the rock), and carbonate, in a cryptocrystalline matrix of reorganised mud. The coarsest material is usually less than $\frac{1}{20}$ mm in diameter. Some of the opaque granules are detrital. Detrital grains of altered ilmenite in crystallographic intergrowths with an opaque mineral are present in trace amounts. Sphene granules may form up to 5% of the mode. The chief authigenic or secondary effects are the recrystallisation of carbonate, albitisation of plagioclase, patchy development of prehnite, and the general development of chlorite and granular pyrite.

(ii) The labile arenites at the base of the Malongulli Formation, grid reference (988421), show a moderate quartz content of 15%, which is in contrast with the usual Angullong Tuff labile greywackes where quartz is lacking or absent. Of the rock fragments, porphyritic andesites are the most frequent, sometimes forming 45% of the mode. However, fragments of dacite and rhyodacite are conspicuous and form 10% to 15% of the mode. Of the crystal detritus, plagioclase predominates. Pale green augite occurs in minor amounts. The framework of the arenites has been somewhat condensed during burial and deformation of individual grains is sometimes apparent where neighbouring grains meet. Twin lamellae of plagioclase crystals are at times bent, and some quartz grains have fractured. A microcrystalline chloritic matrix occurs as a thin filling between grains. The detrital grains are angular to subangular, the size sorting is moderate. Rock fragments range from less than 0·2 mm up to 2 mm. By increase in the size of rock fragments, the arenites grade into labile conglomerates which have fragments up to 5 mm in diameter.

The arenites higher in the Malongulli Formation, grid reference (970430), have a lower percentage of detrital quartz, typically 1% to 5%, and are finer grained than the arenites at the base of the formation. Crystal detritus, chiefly plagioclase and pyroxene, is dominant over andesitic rock fragments. The sorting for size is fair. The cement is generally chloritic, although patches 1 mm across may be seen where the cement is calcareous and in other cases feruginous.

(iii) The andesites as exposed at grid reference (970428), in the middle of the Malongulli Formation, are either lavas or sill-like intrusives. Typically the andesites have phenocrysts of hornblende, augite, and less commonly, plagioclase, set in a felty groundmass of plagioclase microlites, interstitial chlorite, granular opaques and sphene.

Other Occurrences

In the centre of the Area, three north trending limestone conglomerates can be traced for three or four miles. They cross the Belubula River at the junction of Flyers Creek, grid reference (943495). The conglomerates contain rock fragments of andesite, basalt, shale, siltstone and limestone, reaching a maximum diameter of 1 inch. The conglomerates are often uniform in thickness over considerable outcrop, but may gradually increase in thickness from 10 feet to 100 feet. Between Swallow and Cadiangullong Creeks, the conglomerates are folded into a northward plunging syncline and are joined by six or more conglomerates of similar nature. Interbedded with the conglomerates are hard grey to black shales and siltstones.

Malongulli Formation outcrops over a large area on the east and west slopes leading down to Cadiangullong Creek. Numerous gullies offer good exposures. The outcrops south of the junction of Rodds Creek, grid reference (940535), show a complicated structure due to the development of concentric folding on a mesoscopic and macroscopic scale. The lithologies south of Rodds Creek are dominantly shales and siltstones, at times calcareous, with thin horizons of labile arenite. North of Rodds Creek the lithologies are similar but the structure is simpler with the beds dipping uniformly to the north-east. Approximately 2,000 feet of Malongulli Formation outcrops between Rodds Creek and the overlying Angullong Tuff. The complete section of Malongulli Formation is not exposed. The black shales are frequently fossiliferous, especially in the vicinity of grid reference (937546) ; graptolites are the most abundant fauna, occurring with small brachiopods (see locations CO.1/40, 41, 42, 43). Truncated sedimentary structures and current scours indicate intermittent turbulence.

Shale, siltstone, and minor calcareous sandstone of the Malongulli Formation outcrop along the lower part of Swallow Creek, upstream of the Narambon Fault. The sandstones are usually less than 5 feet thick and weather to a porous crumbly rock often containing small articulate brachiopods, as at grid reference (917530). The structure along this part of Swallow Creek is complicated, due to the presence of several faults and isolated occurrences of intense concentric folding. Intrusion of the diorite body at grid reference (918525), and its associated dykes, has further complicated the relationships.

Hard grey siltstones of the Malongulli Formation outcrop east of the Rowland Syncline underlying the Angullong Tuff, at grid reference (910470). The rocks, although porous due to leaching, are still sufficiently compact to preserve graptolites in fair detail. These grey siltstones are probably the equivalent to the black pyritic siltstones seen elsewhere in the Area. Limestone conglomerates, interbedded with blue-grey to black shale and siltstone and bearing limestone pebbles up to 1 inch in diameter, outcrop in the west limb of the Rowland Syncline, at grid reference (892453). The conglomerates are 600 feet to 1,000 feet below the overlying Angullong Tuff.

Provenance

The source area for the lower arenites at Mandurama Ponds Creek was volcanic in nature, containing andesite, dacite, and rhyodacite volcanic rocks. The abundant quartz, some of which is vein quartz, can be assigned to such a source. There were no rock fragments or crystal detritus characteristic of a metamorphic source. The distance of transport of the detritus of the lower labile arenites was not very great, as concluded by their immaturity of mineral components and texture.

The source area for the middle arenites contained intermediate to basic volcanics, probably *hornblende-pyroxene andesites*. The source for these arenites contrasts with that of the lower andesites in that there are no fragments of dacites or rhyodacites amongst the detritus, and that quartz is less common.

The quartz and feldspar of the shales and siltstones probably came from the volcanic source during quieter periods of sedimentation. The calcareous detritus is of intraformational origin, much of it being fragments of organic tests.

The presence of *hornblende-augite basalt* 400 feet from the base of the Angullong Tuff at grid reference (936553) indicates volcanic activity of a basic nature nearby.

The Malongulli Formation represents generally quiet sedimentation with occasional periods of rapid sedimentation, under somewhat euxinic conditions. It is inferred that a neritic environment existed in the west of the Area probably extending into the east where, as suggested by the very fine grained cherty lithologies, there may have been alternations with a bathyal environment. Deposition was in a subsiding basin, probably at the edge of a eugeosyncline during a quiet period of tectonic activity.

Angullong Tuff

Conformably overlying the Malongulli Formation, the Angullong Tuff consists of a thick sequence of intermediate to basic volcanic rocks and their associated sediments.

Definition. Stevens (1954) : " The Angullong Tuff, named after ' Angullong ' Station (Estate) north of Cliefden Caves, is the uppermost Ordovician formation in the region. It conformably overlies the Malongulli Formation and at some places there is a lateral gradation at the formation boundary. The type area is along the Belubula River downstream from ' Kalimna ' and the formation extends north and east towards Cadia and Junction Reefs respectively. It is not known whether all the formation is exposed in the type area where it is unconformably overlain by Devonian sediments. The maximum thickness is estimated to be at about 1,500 feet, an approximate figure due to complex structures and lack of a well-exposed sequence.

" The section exposed along the Belubula River downstream from ' Kalimna ' shows siltstones and tuffs at the base, followed by andesitic tuffs, andesites, felspathic sandstone and siltstone. "

The formation is at least 8,000 feet in thickness at Cadiangullong Creek ; 5,000 feet within the Area studied, plus a further 3,000 feet immediately to the north (Offenberg, 1963). The volcanic rocks consist of basalts and andesites with tuff and volcanic breccia. Volcanic labile greywacke and greywacke conglomerate predominate in the eastern portion of the Area. There is an overall lateral facies change from a dominantly marine greywacke suite with a small percentage of lavas in the east to a volcanic suite of breccia, tuff and lava in the west. Superimposed on this is a vertical facies change in the west, at ' Angullong ' and ' Millamolong ' Stations, where the base of the formation is represented by texturally sorted volcanic arenite and limestone conglomerate indicating a neritic environment. These lithologies give way vertically to devitrified glassy tuffs and coarse volcanic breccia containing rock fragments up to 18 inches in diameter. In Rodds Creek, at grid reference (955554), a thin coral reef containing in situ halysitids and favisitellids, outcrops for about 20 feet along strike.

Cadiangullong Creek Section

An excellent exposure of the lowest 5,000 feet of Angullong Tuff is offered in Cadiangullong Creek between the Errowanbang-Panuara Road, grid reference (948570), and the upper contact of the Malongulli Formation at grid reference (943553). The sequence consists predominantly of volcanic labile rudites and arenites, with subordinate lavas and minor lutite beds. The epiclastic rocks show sedimentary structures characteristic of the Greywacke Suite (Packham, 1954). The beds dip uniformly at 50° to 60° to the north-east. Soft sediment deformation is seen in the shales and siltstones about 12 feet below the boundary of the Angullong Tuff at grid reference (943553). The style of folds and their relations with the overlying beds are not like those of a slump structure. Formational gliding of the Angullong Tuff over the semiconsolidated Malongulli Formation could cause the observed style of deformation. If so, rising connate water squeezed out of the semiconsolidated muds and silts of the Malongulli Formation owing to superimcumbent load of the Angullong Tuff, could provide the necessary lubricant.

(i) *Rudites.*

The rudites are greywacke conglomerates consisting essentially of fragments of igneous and sedimentary rocks in a greywacke matrix. The rock fragments are commonly angular to subangular with low sphericity. A small percentage of the rudites shows more rounded grains. Angular fragments sometimes reach 6 inches to 8 inches across. The rudites typically form bold outcrops. The rock fragments are of the following types :—

a. Porphyritic basalts and andesites. These can be matched with the volcanics of the sequence. There are three main varieties, spilitised *albite-augite basalt, albite andesite,* and *hornblende-augite andesite.*

b. Shale and siltstone. Fragments of shale and siltstone may be subordinate to the volcanic rock fragments as in most of the greywacke conglomerates, or they may be the only rock fragments as in the intraformational conglomerate or breccias.

c. Limestone fragments. Locally, fragments of limestone occur in the conglomerates ; generally they are less than ½ inch in diameter.

The framework of the greywacke conglomerates is frequently partially or completely disrupted (Pettijohn, 1957), that is, the boulders and pebbles or phenoclasts are not always in mutual contact, but are frequently scattered and isolated throughout the matrix. In such instances the framework on its own would be unstable in the gravitational field, but is supported by the matrix. It seems, therefore,

that the framework and the matrix were deposited simultaneously ; such deposition can be explained by mud flows, or turbidity currents.

The greywacke conglomerates, by decrease in size of the rock fragments, may grade upwards into labile greywackes. One greywacke conglomerate, at grid reference (945554), contains rock fragments of 2 inches in diameter at its base, but the size of the fragments decreases to less than 5 mm at a height of about 2 feet from the base. Finally, after 12 feet of thickness, the rock grades into labile greywacke with a grain size of about $\frac{1}{4}$ mm. The style of graded bedding of this specimen is typical of that produced by differential settling from a turbidity flow (Pettijohn, 1957, p. 171 ; Menard, 1951, p. 9), in contrast to that produced by a waning current.

Horizons of intraformational breccias occur in places throughout the column. The fragments are of shale or siltstone, similar to the shale and siltstone of the formation, and are distributed throughout greywacke or greywacke-siltstone. Most of the fragments are tabular with subrounded corners, while others are well rounded. One example, at grid reference (945556), shows an intraformational breccia arising from the upper section of a slump structure. The fact that the breccias are within labile greywackes and greywacke siltstones suggests that they are due to subaqueous processes. Such processes can be caused by turbidity currents which cause pull aparts, and slumping. Evidence for turbidity current action and slumping has been seen elsewhere in the sequence. Shoaling can also cause fragmentation of the mud and silty layers leading to intraformational breccias.

(ii) *Arenites.*

As mentioned above, the greywacke conglomerates, by decrease in size of rock fragments, may grade upwards into greywackes. However, as most greywacke units are of granule or coarse sand size at their base, the grading leads only to finer greywacke. Unless outcrop is good, it is often difficult to determine widths of individual greywacke units. Throughout the sequence, the relationship of increase in width of beds to increase in grain size is apparent. The bedding units less than 1 cm in width have silt-sized particles as their coarsest detritus.

The greywackes are greenish-grey in hand specimens. The fresh rock is hard, compact, with little or no porosity, and has an uneven fracture. Specks of sulphide minerals sometimes may be seen. The crystal detritus is usually of sand size. It is rare to detect any detrital quartz with the hand lens.

In thin section, the greywackes show a fairly consistent composition. There is some variation in the proportions of the components, but this is mainly a function of grain size, the coarser varieties being richer in rock fragments. The essential components are subrounded to angular grains of plagioclase, clinopyroxene and hornblende with varying proportions of rounded to angular rock fragments, in a silty clay matrix. The detrital quartz content is noticeably low, seldom exceeding 5%. The rock fragments are of the same types as those of the greywacke conglomerates (see above), andesites and porphyritic basalts predominating over the shale and siltstone fragments. At least 70% and probably more than 90% of the detritus is volcanic in origin.

An advanced state of authigenic alteration has, in many slides, made percentage estimates difficult, due to reorganisation of the matrix and infringement of the matrix minerals into the detrital grains. However, the greywackes all lie within the *labile greywacke* field of the M.L.Q. diagram of Packham (1954) (see Fig. 3), M = matrix, L = labiles, unstable minerals and rock fragments, Q = quartz plus chert. It seems appropriate to qualify the term ' labile greywacke ' with the addition of the word ' volcanic ', *volcanic labile greywacke* has specific genetic implications.

(iii) *Shale and Siltstones.*

Well-bedded shale and siltstone form only 15% of the column. Their occurrence is random throughout the sequence. The maximum

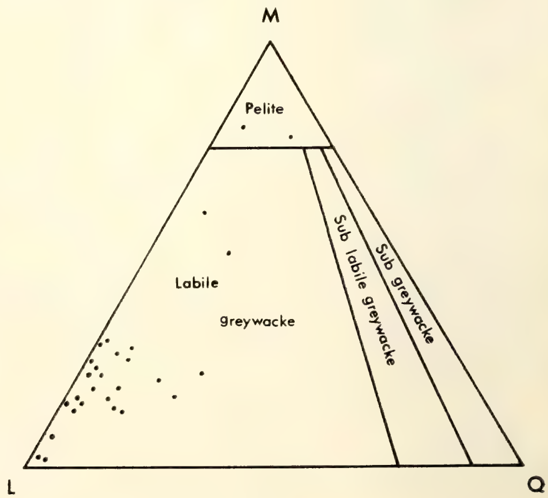


Fig. 3

thickness of any one sequence is 150 feet. The greywacke siltstones plot between the labile greywackes and the pelite field on the M.L.Q. diagram. As the grain size increases, the bedding planes become more widely spaced. The shales and finer siltstones show better sorting than the greywacke siltstones, both in grain size and in recognisable mineral content. Fine siltstones show a quartz content of 10% or 15%, feldspar 20% in a brownish mud matrix containing opaque material, some of which may be organic in origin.

Slumping may be seen in the shale and siltstone beds. The slumped beds range from 9 inches to 2 feet in thickness. At grid reference (945557), the slumps are truncated by erosion of their upper surfaces, indicating that slumping took place prior to or during deposition of the overlying bed.

(iv) *Pyroclastics.*

In the Cadiangullong Creek sequence, pyroclastic tuffs are not common. Most specimens examined could be classified as being either epiclastic or igneous, rather than pyroclastic. It was not possible in the case of two of the slides examined (two out of 40) to decide on an epiclastic or pyroclastic origin. One slide (23128) shows a framework composed almost entirely of devitrified glass shards, with some plagioclase and clinopyroxene fragments cemented by interstitial carbonate, chlorite, prehnite, and ? clay minerals. The delicate shapes of the angular shards are preserved. There is neither evidence of flattening nor of plastic flow after emplacement. The rock, possibly a pyroclastic, may represent volcanic fallout into water as the rock overlies a pillow lava. It could also be a transported tuff, if so, the mechanism of transport was sufficiently gentle so as not to destroy the delicate shards.

(v) *Lavas.*

Lavas form 10% of the stratigraphic column at Cadiangullong Creek. They are intermediate to basic in composition, and all have porphyritic textures. Three different lava types have been recognised, spilitised *albite-augite basalt, hornblende-augite andesite,* and *albite andesite.* Spilitised *albite-augite basalt* forms the major pillow lava which outcrops over a distance of 2½ miles along strike from Panuara, grid reference (926578), to Cadiangullong Creek, grid reference (945555). Large euhedral phenocrysts up to 5 mm in length of light coloured plagioclase and dark pyroxene are characteristic and easily seen in outcrop. The lava is approximately 200 feet thick at Cadiangullong Creek. The lower 100 feet is massive lava and rests conformably on shale which has been indurated for about 1 inch next to the contact. In the upper part of the lava, pillow structures are developed. The pillows reach 5 feet in diameter, adjacent pillows being separated by a thin band of interpillow matrix, varying from ½ inch to 3 inches in thickness and consisting of indurated mud layers and volcanic debris. The actual chilled margin of the pillow lava is thin, being ¼ inch to ½ inch across, and is seen as pale groundmass due to the development of authigenic chlorite and prehnite. The plagioclase phenocrysts are now albite, containing large patches of prehnite, chlorite and carbonate. Mosaics of quartz aggregates may be in part pseudomorphic after pyroxene, although pale green augite, in many cases, is free from alteration. The groundmass is hyalopilitic or pilotaxitic with sub-aligned euhedral albite laths. The mesostasis consists of chlorite, feldspar, sphene and opaque dust. The mesostasis, at times, has the appearance of devitrified glass. Some of the chlorite mesostasis may be pseudomorphic after mafics.

'Angullong' Station

Angullong Tuff is exposed in a broad belt extending from 'Angullong' homestead to the Belubula River with a total thickness in excess of 3,500 feet. The upper part of the Angullong Tuff is transgressed by the Silurian Panuara Formation with which its boundary is either unconformable (as it is one mile to the west), or is faulted. Outcrop is only fair and the thicknesses have only been calculated off the map as dip readings are not very abundant. The formation has been folded into a series of gentle synclines and anticlines which plunge north at about 40°.

Dominant amongst the lithologies are coarse fragmental rocks. Many of these are volcanic breccias, although thin sections are sometimes required to distinguish these from labile greywacke conglomerates. The rock fragments are almost exclusively of andesitic lavas. Shale and siltstone fragments are scarce.

The Angullong Tuff on 'Angullong' Station shows characteristics which contrast with those at Cadiangullong Creek Section. The sequence is composed dominantly of volcanic breccias with minor andesitic lava. Labile greywackes and greywacke conglomerates appear to be absent in the upper member, Member B, their place being taken by the coarse pyroclastics. The lower member, Member A, consists of

conglomerates, some of which have limestone pebbles, with subordinate shale and siltstone.

Member A.

The lowest 1,000 feet of Angullong Tuff consists of 60% limestone conglomerate, and 40% shale and siltstone. The conglomerates contain limestone pebbles 1 inch to 2 inches in diameter ; the matrix is feldspathic. Limestone pods develop at grid reference (908519), where pods of limestone up to 3 feet long and 9 inches thick show a lateral facies change into impure limestone and calcareous siltstone. This calcareous horizon is only 5 feet in maximum thickness but can be traced laterally for about 1,000 feet. The shales and siltstones become increasingly scarce higher up in the sequence. They are typically black and hard when fresh, but weather to a buff colour ; some are lighter in colour and are calcareous.

Member B.

The upper portion of the Angullong Tuff exposed has been grouped as one member 2,500 feet or more in thickness. It consists mainly of coarse fragmental rocks. A traverse along one gully, grid reference (885515), which offered good exposure of volcanic breccia revealed only one siltstone horizon 3 feet thick occurring near the top of the exposed sequence. The coarse fragmental rocks contain andesitic fragments up to 6 inches or 10 inches in maximum diameter set in a matrix which is deeply weathered. The fragments show various states of angularity, ranging from angular to subrounded, such variations being observed within one exposure. Several andesitic bodies occur throughout the upper member ; probably all are lavas.

'Millamolong' Station

East of Limestone Creek on 'Millamolong' Station, the Angullong Tuff occurs as a keel to a major syncline, the 'Rowland Syncline'. About 1,200 feet of sequence is preserved. At the base of the sequence, medium to coarse clastic sediments overlie hard grey leached siltstones of the Malongulli Formation. The sequence shows a vertical change from sandy volcanic epiclastics at the base to pyroclastics and extrusives higher up.

The lowest member is a labile arenite rich in volcanic crystal detritus and lava fragments. Rock fragments may reach 4 mm in diameter. The fragments consist of *hornblende-augite andesite* and *plagioclase-hornblende andesite.* Shale and siltstone fragments are lacking. The crystal detritus consists of plagioclase, hornblende, augite and some detrital opaques.

Above the labile arenite member is a sequence of andesitic pyroclastics and lavas. The first lithology is a fine volcanic breccia approximately 60 feet thick and has andesitic fragments up to 1 inch in diameter set in a feldspathic crystal tuff matrix. The rock fragments are of one type, namely spilitised *albite-hornblende andesite* ; the tuffaceous matrix consists essentially of the same minerals as those forming the rock fragments. This volcanic breccia is overlain by interbedded crystal tuff and more volcanic breccia of a similar nature.

Metamorphism

The lavas, greywackes and greywacke conglomerates of the Angullong Tuff all show authigenic development of some assemblage of quartz, prehnite, pumpellyite, epidote, albite, chlorite, carbonate, and sphene. Quartz, prehnite, epidote, chlorite, and carbonate occur as amygdule minerals in the lavas. The extent of authigenesis is more apparent in the arenites, rudites, and in some lavas than in the shales and siltstones.

Within the formation, the plagioclase of all rocks examined is *albite*. Relic zoning of the plagioclase may be recognised in both the lavas and the greywackes by the inclusions of chlorite, prehnite, carbonate, and epidote. The occurrence of calcium bearing silicates within sodic plagioclase is strong evidence for an originally more calcic plagioclase, the calcium released by albitisation being taken up by minerals such as prehnite, pumpellyite, epidote, and carbonate. *Prehnite* may also develop in the matrix of the greywackes and greywacke conglomerates, at times encroaching upon rock fragments and crystal detritus. *Chlorite* may be seen in all slides of the sequence. Chlorite shows various stages of replacement of crystal detritus, matrix, or groundmass of the lavas. Authigenic *carbonate* has been produced in some cases by the albitisation of plagioclase. Some carbonate, however, was detrital as shell fragments, limestone pebbles or as calcareous matrix. The detrital carbonate frequently shows reorganisation and secondary overgrowths into the matrix. *Pumpellyite* occurs as a secondary mineral within the plagioclase phenocrysts and in the mesostasis of slides 23124, 23134, 23136.

Allogenic clinopyroxene, pale green augite, is often apparently metastable, and at times may

persist after plagioclase, hornblende and rock fragments have been extensively altered to assemblages of chlorite, prehnite, epidote, and carbonate. However, slight marginal alteration and alteration along cleavage planes of augite to either albite, prehnite, chlorite or carbonate are not uncommon.

Provenance

The rocks of the Angullong Tuff have essentially the same provenance. The detritus of the labile greywackes and greywacke conglomerates at Cadiangullong Creek contain rock fragments of porphyritic basalts and andesites with subordinate fragments of shale, siltstone and limestone. Rock fragments of plutonic and metamorphic lithologies are absent. The rock fragments are therefore either of intraformational origin or are correlatable with a volcanic source of intermediate or basic nature. The crystal detritus is in agreement with such a source. There has been little or no mineralogical sorting of detritus during transport and deposition. The rocks are also texturally immature. Submarine mud flows, slumps and turbidity currents are believed to be the prime methods of transport. The supply of detritus must have been rapid and abundant to enable unstable minerals and rock fragments to survive. Poorly consolidated lithic tuffs could provide a source of angular fragments and such a source could be rapidly eroded. Eruptions of submarine breccias may have also been a major process for the introduction of coarse angular lava fragments into sedimentary detritus. The general instability of such a volcanic island ridge would provide opportunities for the triggering off of submarine slides, turbidity currents, and slumps. Slump structures, at grid reference (944556), 1,400 feet from the base of the Angullong Tuff indicate a down slope direction to the east. Scant field evidence suggests a direction of provenance to the west. In the Area studied, there does not seem to be any decrease in rock fragment size away from the source region.

Not all the greywacke conglomerates seen in the Area show grading. Many, containing coarse material several inches in diameter, are ungraded even over outcrop thickness of 10 feet or more. These greywacke conglomerates usually have a disrupted framework. It appears that, due to the effective density and viscosity of the suspension, rock fragments were not able to settle in a graded fashion. The grading or settling is said to be a function of the solid-fluid ratio (Pettijohn, 1957), that is, the framework to matrix ratio. The framework to matrix ratio of a greywacke conglomerate at grid reference (943553), which shows grading of rock fragments from a maximum of 2 inches diameter to sand sized particles of 0·2 mm diameter over a thickness of 12 feet, is 3 : 1. That of an ungraded greywacke conglomerate is 7 : 1. Another ungraded greywacke conglomerate has a ratio of 5 : 1. It is probable that these ungraded, unsorted greywacke conglomerates are the products of mud flows whose solid to fluid ratio was too high for Newtonian settling to allow grading of the components (Pettijohn, 1957, p. 591).

The lower member at ' Millamolong ' Station is a clean washed, shallow-water, volcanic sandstone. The textures of the overlying tuffs and volcanic breccias indicate that they were hot when deposited as seen by the plastically deformed fragments. As the water was already shallow during the deposition of the basal member of the Angullong Tuff, it seems likely that the rapid addition of 1,200 feet or more of volcanic material would exceed the rate of subsidence and consequently the deposition surface may have risen above sea-level. It is therefore likely that much of the sequence is terrestrial, the product of direct volcanic fallout, ash flows, and fragmental lavas.

The basal member of the Angullong Tuff at ' Angullong ' Station seems to represent deposition in a shallow neritic environment as seen by the presence of corals, brachiopods, and limestone conglomerates. The rapid influx of 2,500 feet or more of tuffs, volcanic breccias and lavas no doubt also raised the deposition surface above sea-level in this domain. The presence of very coarse blocks of lava 6 inches to 10 inches in diameter in the volcanic breccias suggests a proximity to the source.

Environment of Deposition

Immediately prior to the rapid influx of volcanic material which marks the base of the Angullong Tuff, which is Eastonian in age (Moors, 1963), a neritic environment extended over most of the Area. A nearby region, probably near the west of the Area, was undergoing uplift, resulting in widespread limestone conglomerates. The lowest beds of the Angullong Tuff are seen in the centre of the Area as marine labile greywackes at Cadiangullong Creek and as marine labile volcanic sandstones and limestone conglomerates in the west of the Area. As deposition proceeded, the sequence at Cadiangullong Creek remained submarine. The lowest members of the

Angullong Tuff at 'Angullong' and 'Millamolong' Stations in the west of the Area were deposited in shallow water, and as accumulation of volcanic material proceeded, the deposition surface rose above sea-level, resulting in the unsorted volcanic breccias, tuffs and lavas, which form the upper members.

The absence of typical continental sediment in the Angullong Tuff indicates that there was no continental land mass nearby shedding sediment into the deposition area. An island shore line, however, did exist during deposition of the base of the Angullong Tuff. A further 12 miles to the west, the marine epiclastic Millambri Formation is equivalent to the Angullong Tuff. From east to west we obtain the lateral facies change from marine Millambri Formation through the shallow water and terrestrial Angullong Tuff at the western margin of this Area, to the marine dominantly epiclastic Angullong Tuff in the east (see Fig. 5). The Angullong Tuff was associated with a north-south trending volcanic island chain passing through the western margin of the Area.

Panuara Formation

Definition. Stevens (1954): "The Panuara Formation, which takes its name from Panuara Rivulet, an alternative name for Four Mile Creek, consists of shales, siltstones and sandstones, with one or two limestone beds near the base. The type area is on Bridge and Bull's Camp Creeks and on Panuara Rivulet. The total thickness in this area is about 2,000 feet. Fossiliferous Silurian rocks from Lower Llandovey (Lower Silurian) to upper Wenlock (Upper Silurian) are included in the formation".

That part of the Panuara Formation exposed consists of khaki shales and siltstones with grey to red sandstones. A thin horizon of limestone conglomerate and associated coral fauna (including halysitids and favositids CO.1/51) outcrop halfway up the sequence at grid reference (908540). Approximately 3,000 feet of Panuara Formation intermittently outcrops. The boundary with the underlying Angullong Tuff is poorly exposed but is not concordant and may be faulted. Three miles to the northwest, in the Cobblers Creek Syncline, the Panuara Formation unconformably overlies the Angullong Tuff. The lithologies present within the Area belong to the arkose-quartzose-sandstone suite (Packham, 1954).

The lowest 1,000 feet consists of fine grained, even textured, khaki sandstone, with thin interbedded khaki siltstone and shale, overlain by 1,200 feet of sandstone lithology with subordinate khaki shale, minor limestone conglomerate and impure calcarenite. The sandstone is further overlain by 500 feet to 1,000 feet of dominantly well-bedded khaki and buff shales and siltstones. The shales are very weathered and crumbly in outcrop with limonite enriched layers along bedding planes and joints. Varieties of *Monograptus tumescens* indicate a Melbournian or Upper Silurian age, for the top of this sequence exposed, grid reference (904559), location CO.1/44. Associated with the graptolite fauna are fragments of trilobites and small brachiopods.

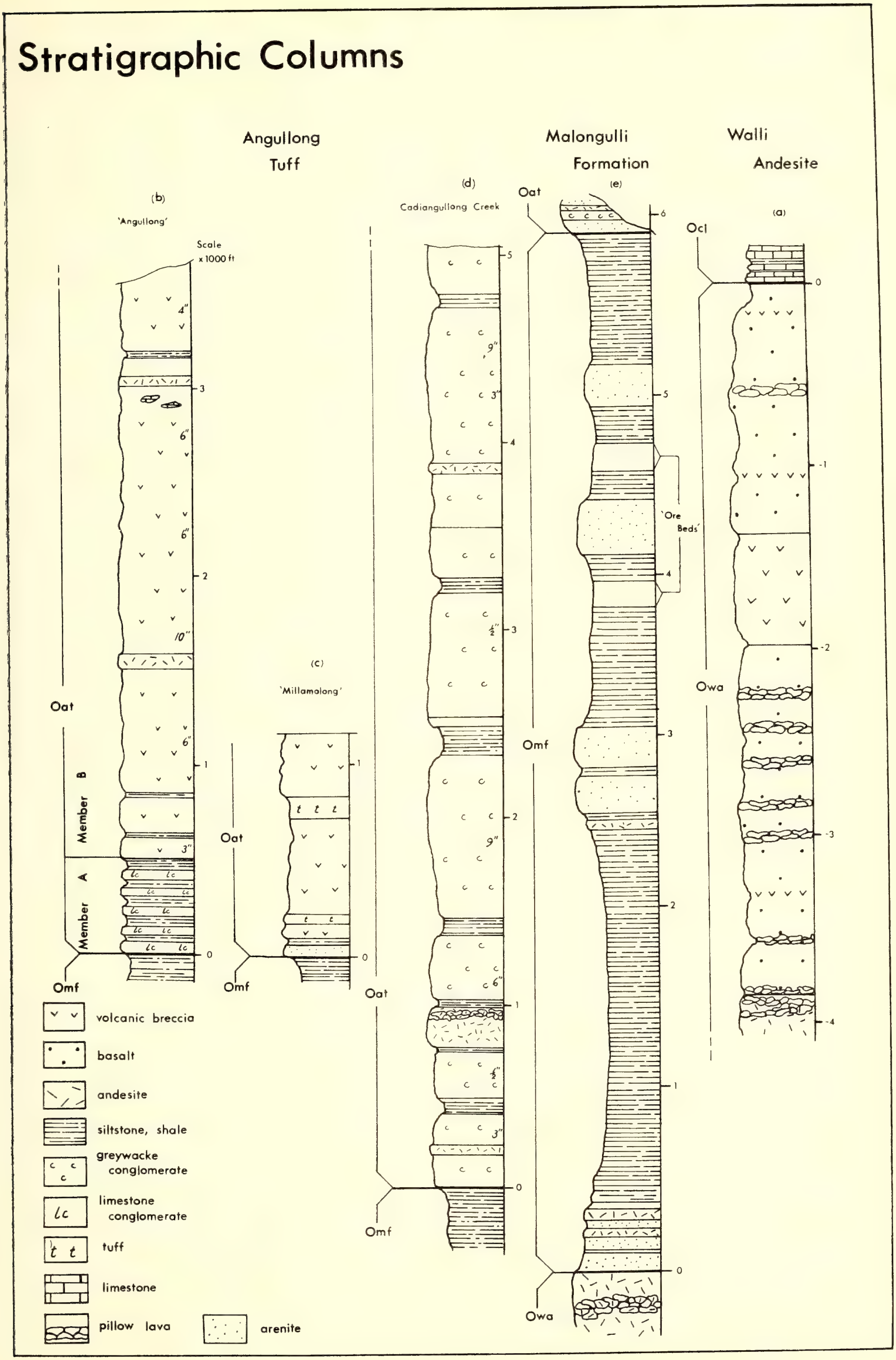
The presence of graptolites indicates a marine environment, in addition, the presence of in situ corals indicates that at times the environment was epineritic. Oxidising conditions existed as seen by the presence of abundant haematite granules in the cement, the breakdown of the haematite results in the general khaki appearance in outcrop. Deposition apparently took place on the shelf margin of an open basin.

Regional Metamorphism

The Ordovician rocks of the Area have been subjected to low grade metamorphism leading to the formation of secondary minerals, similar to those of the *prehnite-pumpellyite metagreywacke* facies described by Coombs (1960). The metamorphism is presumably due to a rise in temperature and pressure during burial. The oldest sequence of volcanics, the Walli and Mount Pleasant Andesites, shows the assemblage of quartz, albite, epidote, prehnite, pumpellyite, chlorite, carbonate, and sphene.

In addition to this assemblage, tremolite-actinolite is present in some slides from the Mount Pleasant Andesite, at grid reference (989412). The assemblages of the stratigraphically higher Ordovician formation in the Area, the Angullong Tuff, is apparently the same, except that prehnite is more extensively developed and pumpellyite is scarce. The rocks, in general, show undeformed fabrics; relic textures are usually visible despite the extensive development of secondary minerals.

As a first approximation one can assume uniform thicknesses of formations over a limited area. There are, however, limitations to this assumption, as the Malongulli Formation, for example, is known to wedge above the Cliefden Caves Limestone, see Fig. 5. Five thousand


Stratigraphic Columns
Angullong Tuff
Malongulli Formation
Walli Andesite
(b)
'Angullong'
Scale x 1000 ft
(c)
'Millamolong'
(d)
Cadiangullong Creek
(e)
'Ore Beds'
(a)
Oat
Omf
Owa
Ocl
Member B
Member A
volcanic breccia
basalt
andesite
siltstone, shale
greywacke conglomerate
limestone conglomerate
tuff
limestone
pillow lava
arenite

feet of Angullong Tuff outcrop within the Area at Cadiangullong Creek. Added to this thickness is a further 3,000 feet or more adjoining to the north (Offenberg, 1963). The Malongulli Formation at Mandurama Ponds Creek appears to be approximately 5,000 feet thick. These figures give a minimum of 13,000 feet overlying the Walli and Mount Pleasant Andesites. Added to this estimate is the sequence of Silurian rocks which, from nearby field evidence, may add a further 2,000 feet or 3,000 feet. Younger formations are markedly unconformable on the Ordovician and Silurian formations and their relation to burial is more obscure. It seems, therefore, that the maximum depth of burial of the Walli and Mount Pleasant Andesites was in excess of 16,000 feet.

In southern New Zealand, Coombs (1954) shows prehnite first appearing at a depth of burial of 23,000 feet, pumpellyite first occurring higher at 16,000 feet. Calcic plagioclase had almost completely gone over to albite by a depth of 17,000 feet. Crook (1960) at Wahgi Valley, found prehnite and pumpellyite at a depth of burial of 16,000 feet to 17,000 feet, and found albitised feldspar at the top of the sequence at 13,000 feet of burial.

In the Mandurama-Panuara Area, the Ordovician Formations belong to the prehnite-pumpellyite metagreywacke facies. The partly unconformable Silurian formations show authigenic albite, chlorite, but neither prehnite, pumpellyite nor epidote is present. The Silurian lithologies are somewhat different in composition to the Ordovician formations which are richer in labiles. As yet the relationship of metamorphism to varying lithologies is not clear.

In the Permian rocks of the South Coast of New South Wales, Raam (1964) noted the occurrence of prehnite and pumpellyite, associated with laumontite, under a calculated 3,000 feet of burial. Otalora (1964) records the occurrence of prehnite-pumpellyite in his Rio Loco Formation which consists of andesitic lava flows, flow breccias, and volcanic breccias. The calculated depth of burial is again low, being no more than 6,000 feet.

Intrusive Bodies

Prince of Wales Diorite

Fig. 6A.

The Prince of Wales Diorite is an intermediate to basic, medium to fine grained intrusive which outcrops between Junction Reefs and Burnt Yards, grid reference (970470). The name is taken from the discontinued 'Prince of Wales' Mine at the north-east margin of the intrusive. The Prince of Wales Diorite is the largest intrusive body outcropping in the Area, being about $1\frac{1}{2}$ miles across at its narrowest diameter. The body has a general boss-like outcrop, with minor cupolas in the south at Junction Reefs, grid reference (960440). The lithologies are dioritic to andesitic in character, two varieties being present. A porphyritic variety forms more than 60% of the exposed body. The aphyric variety occurs as several isolated bodies located near the margins of the porphyritic variety, as shown in the map. The largest aphyric diorite body is roughly $1\frac{1}{2}$ miles long and 1 mile wide, outcropping about 1 mile north of Junction Reefs, grid reference (968454). As seen from the outcrop pattern, the porphyritic variety does not seem to be a simple marginal facies of the aphyric diorite. The two varieties may represent two different intrusive occurrences.

The aphyric diorite is classified as a uralitised augite diorite or augite microdiorite and reaches a maximum grain size of 4 mm. The average mode is given in Table I*a*.

Anhedral orthoclase is frequently subophitic with euhedral plagioclase and pyroxene. Simple zoning is shown by the plagioclase, which has cores of labradorite An_{55} and rims of more sodic plagioclase, oligoclase An_{20}. Euhedral to subhedral pale green augite is partly replaced by tremolite-actinolite. Biotite, when present, also shows partial alteration to tremolite-actinolite.

Slide 23161 shows pale green tremolite-actinolite, or uralite in various stages of replacement of augite, frequently the tremolite-actinolite forms a margin around relic augite, and in some cases the pyroxene has been pseudomorphed. Many uralite patches contain opaque granules, probably representing iron released during the alteration. In one instance, augite shows replacement by uralite and calcite. Minute sphene euhedra about 0·02 mm in diameter accompany the uralitisation. Although at times apparently optically continuous, the tremolite-actinolite pseudomorphs are usually composed of tightly packed fibres having a common orientation. The plagioclase shows extensive alteration typically to a felty mass of white mica, and in other cases to a white mica and tremolite-actinolite. The alteration of the plagioclase shows a preference for the cores which are more calcic than the rims. The orthoclase is clear except for patches of pink-brown clay products.

The average mode for the porphyritic intrusives is given in Table I*b*. The porphyritic lithologies vary in coarseness of the groundmass and have been classified as uralitised porphyritic *augite microdiorites* and *augite andesites*. The phenocrysts of plagioclase and augite reach a maximum size comparable with that of the aphyric varieties, namely 1 mm to 4 mm. The groundmass is either granular or felty, and contains plagioclase, oligoclase An_{25}, tremolite-actinolite, interstitial chlorite, granular opaques, and a trace of biotite.

As the Prince of Wales Diorite outcrops in the vicinity of the Junction Reefs Goldfield, the possibility of a relationship between the intrusive (or intrusives) and the genesis of the ore bodies has been investigated. The ore bodies at Junction Reefs occur over an area intruded by minor cupolas of the Prince of Wales Diorite. Sulphide mineralisation occurs with a gangue of tremolite-actinolite and carbonite. The mineralised " ore-beds " which appear to be altered labile calcareous greywackes occurring with altered siltstones of the Malongulli Formation also show development of sulphides, tremolite-actinolite, and carbonate. Sulphide mineralisation occurs again at the north margin of the Prince of Wales Diorite, at the ' Prince of Wales ' Mine.

Sulphide minerals occur among the opaques of the diorite and microdiorites, all varieties of the pluton show accessory opaques. However, in the porphyritic varieties, the percentage of opaques is higher and averages about 10%. Possible relations between the Prince of Wales Diorite and the mineralisation which lead to the formation of the ore bodies cannot be disregarded.

Minor Intrusives

Fig. 6, C, D, E and F.

Several minor intermediate porphyritic intrusive bodies outcrop in the Area, viz at grid references (925510), (918520), and (958426). All show alteration leading to the formation of secondary minerals similar to those formed in the regional alteration or metamorphism of the Ordovician formations into which the bodies have intruded, and for this reason are considered to have been intruded before or during the metamorphism. The development of patches of prehnite, chlorite, epidote, and carbonate contained within albite is good evidence for the albitisation of an originally more calcic plagioclase. These minerals may also occur as alteration products of the mafic minerals. In slide 23167, from grid reference (925514), the amphibole has in some examples been pseudomorphed by epidote, and to a lesser extent by chlorite. Tables I*c*, *d*, *e*, gives approximate modes of the intrusives.

The microdiorite body which outcrops on the eastern slopes leading down to Swallow Creek, between that creek and Cadiangullong Creek, at grid reference (918520), narrows in outcrop southwards until at a minimum width of 100 yards, then widens gradually after crossing the river. The maximum width of the body on the south side of the river is 400 yards, on the north side it is about 500 yards. Along Swallow Creek, in the vicinity of grid reference (915525), numerous dykes and minor intrusive offshoots of the main body outcrop in the creek bed and in the side gullies and cut across shale and siltstone of the Malongulli Formation.

The bodies are interpreted as being metamorphosed *quartz microdiorites*. Their composition is similar to that of some of the *plagioclase-hornblende andesites* which occur in the Angullong Tuff. The dominant textural difference is the more coarse groundmass of the microdiorites. The microdiorites may be magmatically related to the *plagioclase-hornblende andesites*.

Errowan Syenite

Fig. 6, B.

One mile north-west of ' Errowan Park ' Station, a medium to coarse grained intermediate igneous body has intruded the Ordovician Angullong Tuff, grid reference (000550). The rock is deeply weathered over much of the outcrop. The outcrop pattern is partly obscured by an overlying unconformable series of Tertiary lavas.

The rock is an oversaturated syenite or quartz syenite. The texture is hypidiomorphic-granular, with an average grain size varying from 5 mm to 2 mm. Euhedral pyroxene outlines are visible, although in some cases the pyroxene is pseudomorphed by tremolite-actinolite. Relic islands of augite are sometimes seen at the centres of the altered pyroxene. Alteration of the pyroxenes may produce optically continuous pseudomorphs of amphibole, or ragged patches of acicular tremolite-actinolite intergrown with chlorite, epidote and opaques. The plagioclase, which has the composition of albite An_0 to An_{05}, is peppered with alteration to tremolite-actinolite, chlorite, and minor patches of prehnite. Polysynthetic twinning is barely visible due to the alteration. Microperthitic K-feldspar occurs as anhedral patches subophitically enclosing plagioclase,

pyroxene and anhedral quartz. Table I*f* gives an approximate mode for the Errowan Syenite.

Weemalla Diorite

One quarter of a mile east of the Panuara-Angullong Road, and one mile north-east of 'Angullong' Station, a small aphyric intermediate igneous body outcrops, grid reference (898540). The boss-like body is less than half a square mile in area, and has intruded Silurian sediments. The rock has been classified as a medium grained allotriomorphic-granular *augite-quartz microdiorite*. The plagioclase occurs as simply zoned subhedral laths arranged to give a felty texture. The composition of the plagioclase lies in the andesine class, except for the outer margin of each lath which is oligoclase. Subhedral to anhedral colourless augite tends to accumulate in aggregates. White mica and biotite occur as ragged patches throughout the rock. Chlorite occurs as a replacement of biotite, and, to a lesser extent, of augite. An approximate mode of this Weemalla Diorite is given in Table I*g*.

Structure

Field mapping shows that the Area can be divided into two major blocks. The western block, Block I, is about 20 square miles in area, and is bounded in the east by the Narambon Fault, and in the south-east by a region of poor outcrop. The second block, Block II, consists of the eastern two-thirds of the Area, containing about 30 or 40 square miles. Block II is divided into subordinate sections by the major north-south trending Wongalong Fault.

Block I. In the west of Block I, the Walli Andesite and Cliefden Caves Limestone are separated from the main section of this block by a fault trending 330°. Bedded rocks of the Cliefden Caves Limestone terminate abruptly along strike against shales and siltstones of the Malongulli Formation. The fault outcrops in a gully at grid reference (899402), one quarter of a mile north of the Mandurama-Canowindra Road, where an 800 feet wide shear zone of folded slates and phyllites outcrops.

The remainder of Block I is a structurally continuous unit, except perhaps for the extreme northern section of Panuara Formation, which may be faulted against the Angullong Tuff. The Rowland Syncline outcrops in the south of Block I. The west limb, dipping at an average of 20° or 30°, has a more gentle dip than the east limb which dips at 45° to 50°. The lowermost beds of the Angullong Tuff are preserved in the keel of the syncline and conformably overlie the Malongulli Formation. The syncline shows an overall plunge of 15° to 155°. The north section of Block I shows a series of gently folded synclines and anticlines of Angullong Tuff plunging north at angles ranging from 20° to 34°. Deformation is by concentric folding; no cleavage being developed. The folds show undulation of the hinge areas and the folds tend to die out along strike of their axes into the limbs of other folds.

The Narambon Fault

A subvertical dyke-like body has been mapped continuously from the Belubula River northward over a distance of one mile. The 'dyke' is 10 feet to 20 feet across and contains brecciated cherty siltstone cemented by quartz-barite mineralisation. The siltstone fragments are typically less than one inch in diameter, and are similar to siltstones of the Malongulli Formation. The 'dyke' forms a prominent ridge, sometimes rising 10 feet above less resistant country rock. Further northwards, the 'dyke' gives way to smaller 'dykes' of similar nature. The 'dykes' are mineralised shear zones. Several other shear zones occur subparallel in strike to the main 'dyke'. Within the 'dykes' minor mineralised veins 1 foot to 2 feet across, containing 60% to 90% barite, occur but are discontinuous. Bedding has been deformed in the neighbourhood of the 'dykes' by complicated concentric folds and small faults. Small blocks of Ordovician and Silurian formations have been isolated by zones of shearing at grid reference (910530). On the macroscopic scale, as seen on the map, Angullong Tuff and Panuara Formation have been cut sharply by the 'dyke' bodies, and along strike adjoin the Malongulli Formation. It is concluded that the dyke-like bodies represent the positions of faults and are mineralised *fault breccias*. It appears that faulting was not restricted to a single plane of movement, but occurred over a zone 800 feet to 1,000 feet wide. The fault zone has a trend of 350°, within this zone is a series of echelon component faults with a more westerly trend of 330° to 340°. The fault zone outcrops intermittently over a distance of five miles, disappearing at either end into areas of poor outcrop. The displacement of the Narambon Fault is not known.

Block II. Angullong Tuff forms a major part of Block II. In the north of Block II, beds of the Angullong Tuff strike north-west and dip at 40° to 50° to the north-east. The formation boundary with the underlying Malongulli Formation strikes north-west at the north-west part of this block in accordance with the strike of the beds. However, at Rodds Creek, grid reference (952550), the formation boundary swings sharply to a north-south direction and the Angullong Tuff cuts across the trend of the Malongulli Formation. The boundary continues with a north-south trend for six miles, during which distance the trend of the Malongulli Formation swings and becomes subparallel to the trend of the formation boundary. Two miles north of Junction Reefs, grid reference (947462), the Angullong Tuff/ Malongulli Formation boundary turns again and takes a north-west trend again.

The Wongalong Fault

The discordant relationship of the Angullong Tuff to the Malongulli Formation during the north-south trend of the formation contact mentioned above is due to faulting along the contact. The boundary of the two formations between grid reference (946463) and (952550), is frequently sheared over a zone varying from 10 feet to 70 feet. Shearing is exposed at the Belubula River, grid reference (948477), where several minor faults are exposed in the river bed. Following the formation boundary northward, shearing can be seen in most of the side gullies of Cadiangullong Creek where the gullies cross the boundary. Tight concentric folding and shearing can be seen over a zone of 400 feet in width at Rodds Creek, grid reference (952550). The zone of shearing continues northward along Rodds Creek. More evidence of this fault is seen at grid reference (947520) where the lowest beds of the Angullong Tuff end abruptly westwards along strike against north-south trending beds of the Malongulli Formation. It is concluded that a fault separates the Angullong Tuff and the Malongulli Formation between grid reference (952550) at Rodds Creek in the north, to grid reference (947462) south of the Belubula River. The fault is named the Wongalong Fault. This fault possibly continues northward along the shear zone in Rodds Creek and may join a north-south trending fault of Offenberg (1963) at grid reference (959600), however, outcrop between these two regions is not good. It is possible that the Wongalong Fault continues to the south and may join or be associated with the Marangulla Fault at grid reference (955440).

Minor Faulting

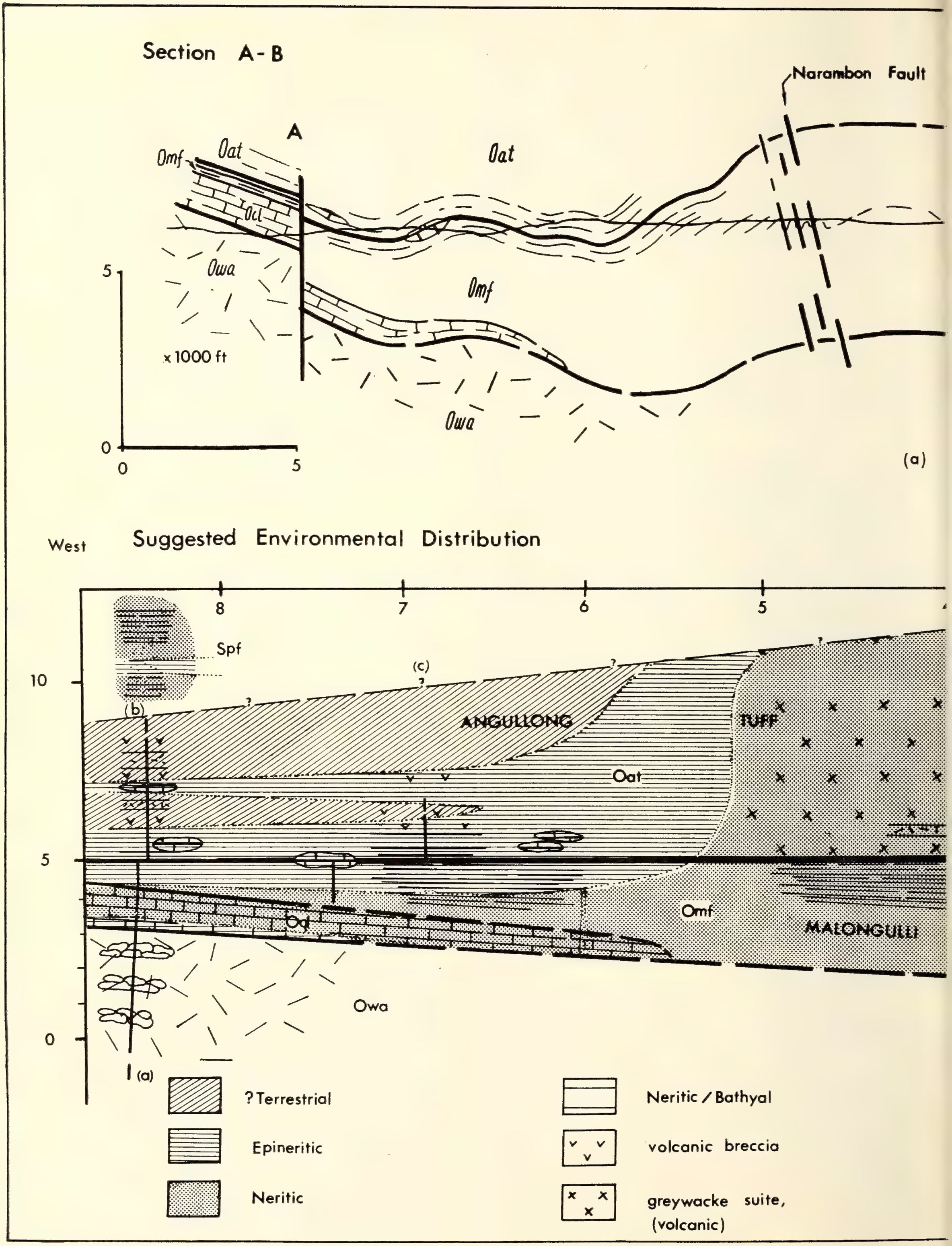
Small scale faults are numerous along Swallow Creek. One fault can be traced intermittently northward from grid reference (920533). A series of limestone conglomerates and greywacke conglomerates, probably representing the base of the Angullong Tuff, are faulted against the Malongulli Formation at grid reference (923539). The fault has a shear zone 5 feet to 10 feet across and contains brecciated shale and sheared greywacke. The shear zone weathers more rapidly than the unsheared rock, and consequently the creek tends to follow the fault. Intense flexural slip folding of the bedded Malongulli Formation at grid reference (920534) occurs in the regions local to the fault. The main fault either bificates or is associated with several minor faults.

Regional Setting

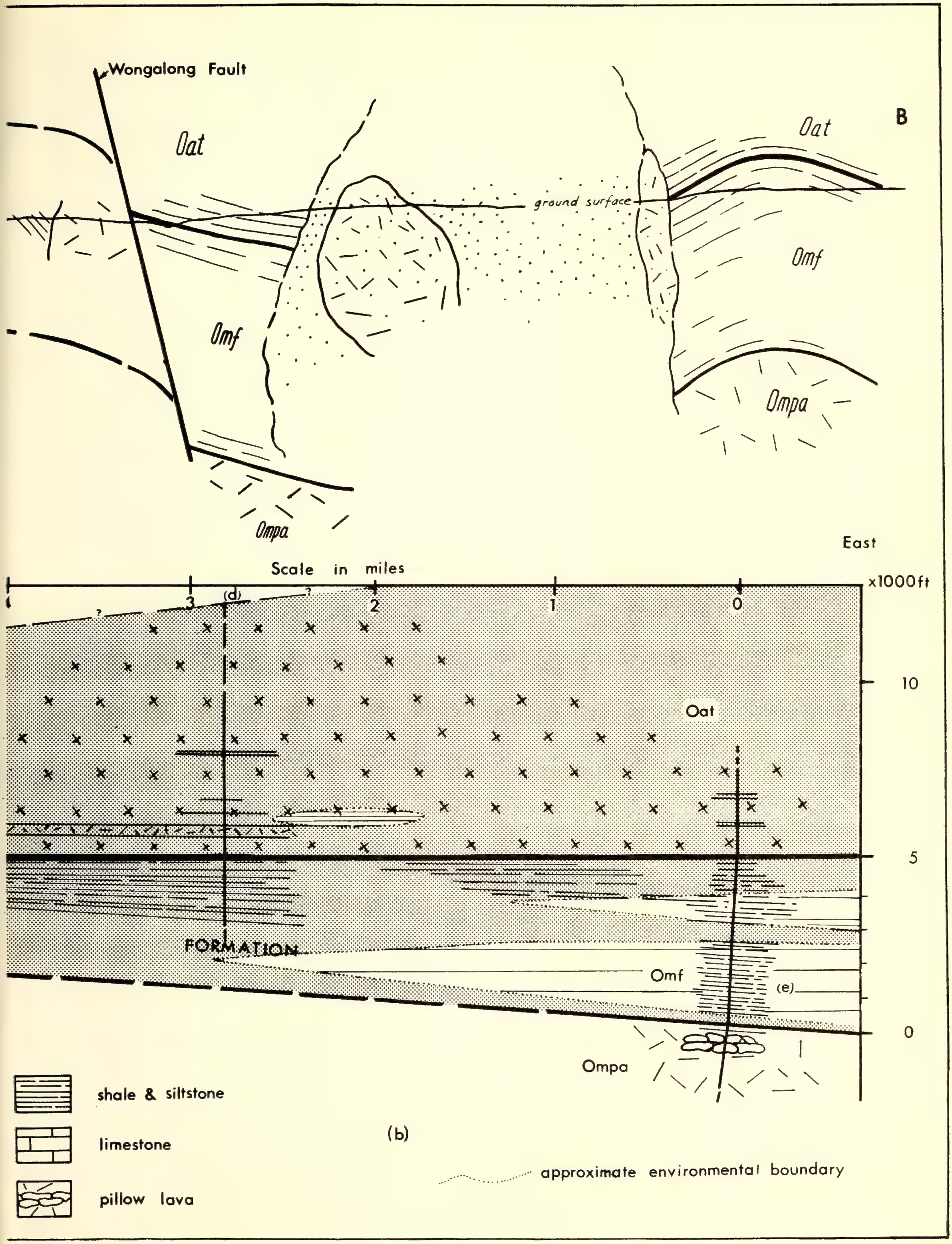
A major volcanic arc dominated sedimentation in the east of Victoria and central New South Wales during Upper Ordovician, through Silurian times until the end of Middle Devonian time. The igneous activity was concentrated along a narrow tectonic zone locally coinciding with a north trending ridge, the Molong Geanticline, which was active and passed through the Central West at Orange and extended northwards through Wellington. The geanticline was generally about 20 miles wide and is characterized by the abundance of limestone. This structure disappears to the south.

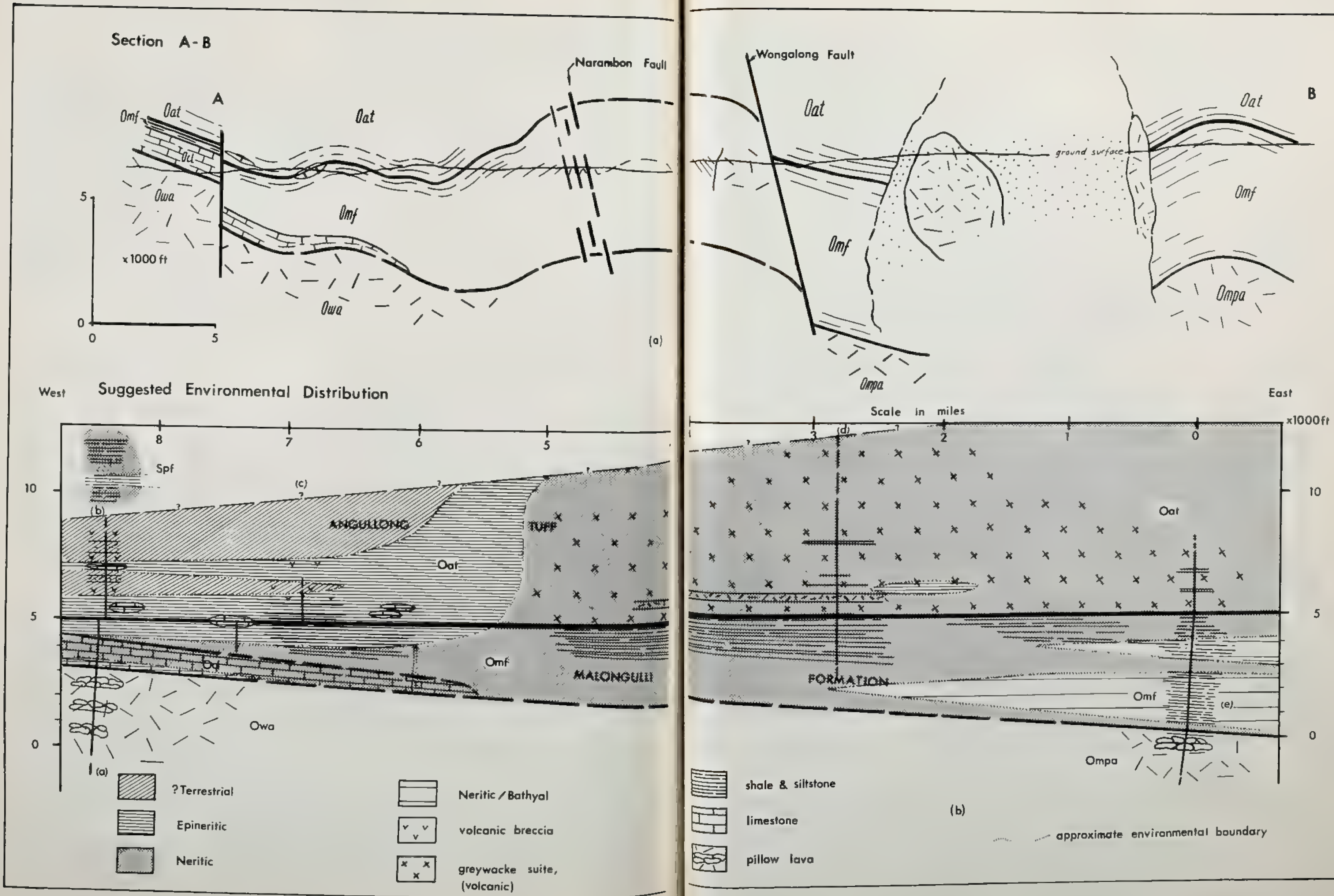
The Mandurama-Panuara Area lies close to and on the east side of the axis of the geanticline. To the west of the geanticline lay the Cowra Trough, and to the east the Hill End Trough, limited further to the east by the Capertee Geanticline. Sedimentation of the Ordovician and Silurian rocks of the Area took place partly in the west margin of the Hill End Trough. The area adjacent to the west shows a shallow shelly facies at Middle Ordovician time. Apparently vulcanism during Middle Ordovician and Upper Ordovician times was confined to the east side of the Molong Geanticline as lavas are lacking in the area studied by Ryall, 15 miles to the west (Ryall, 1963).

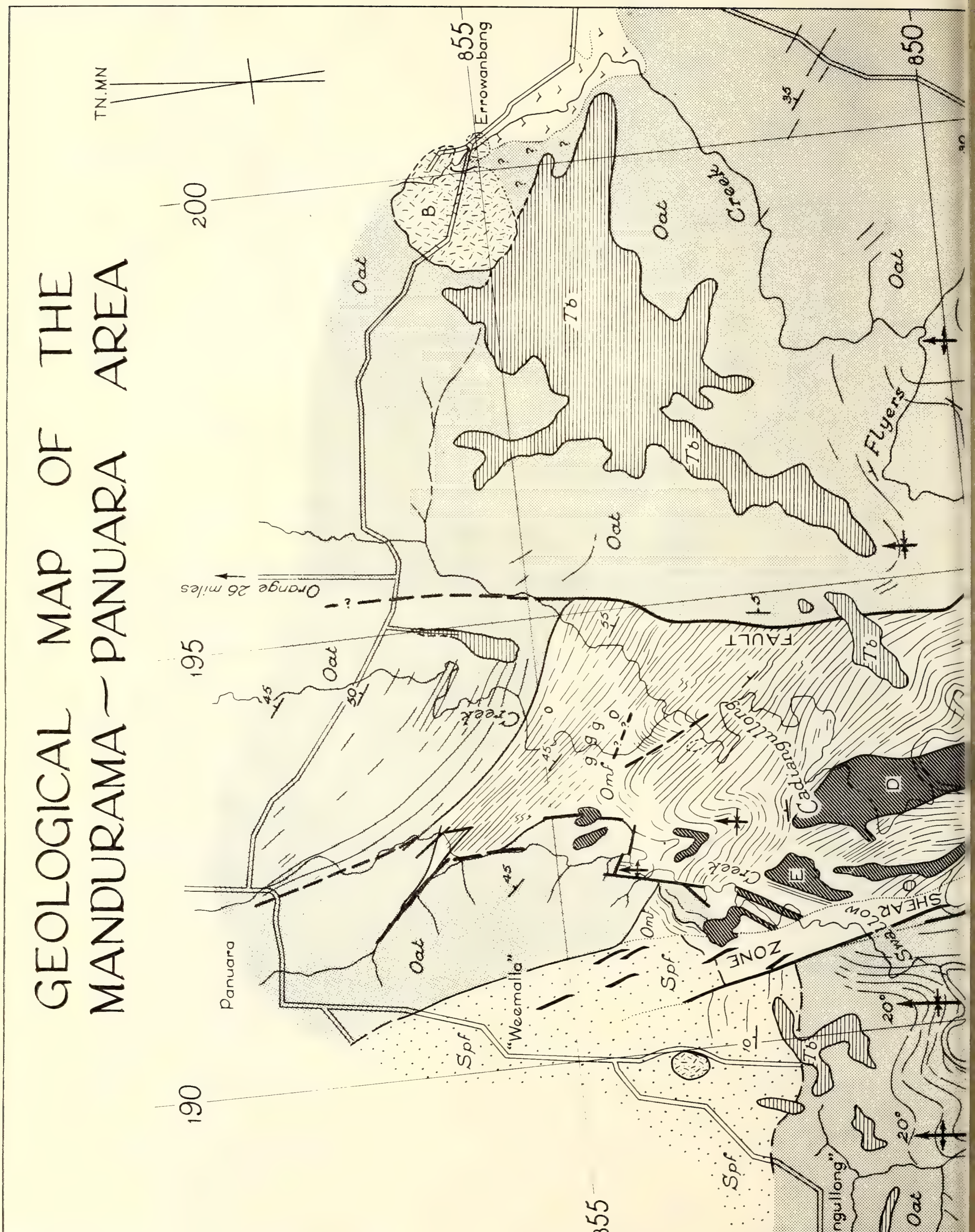
During the period of activity of this volcanic arc there were periods of quiescence and stability with the development of isolated

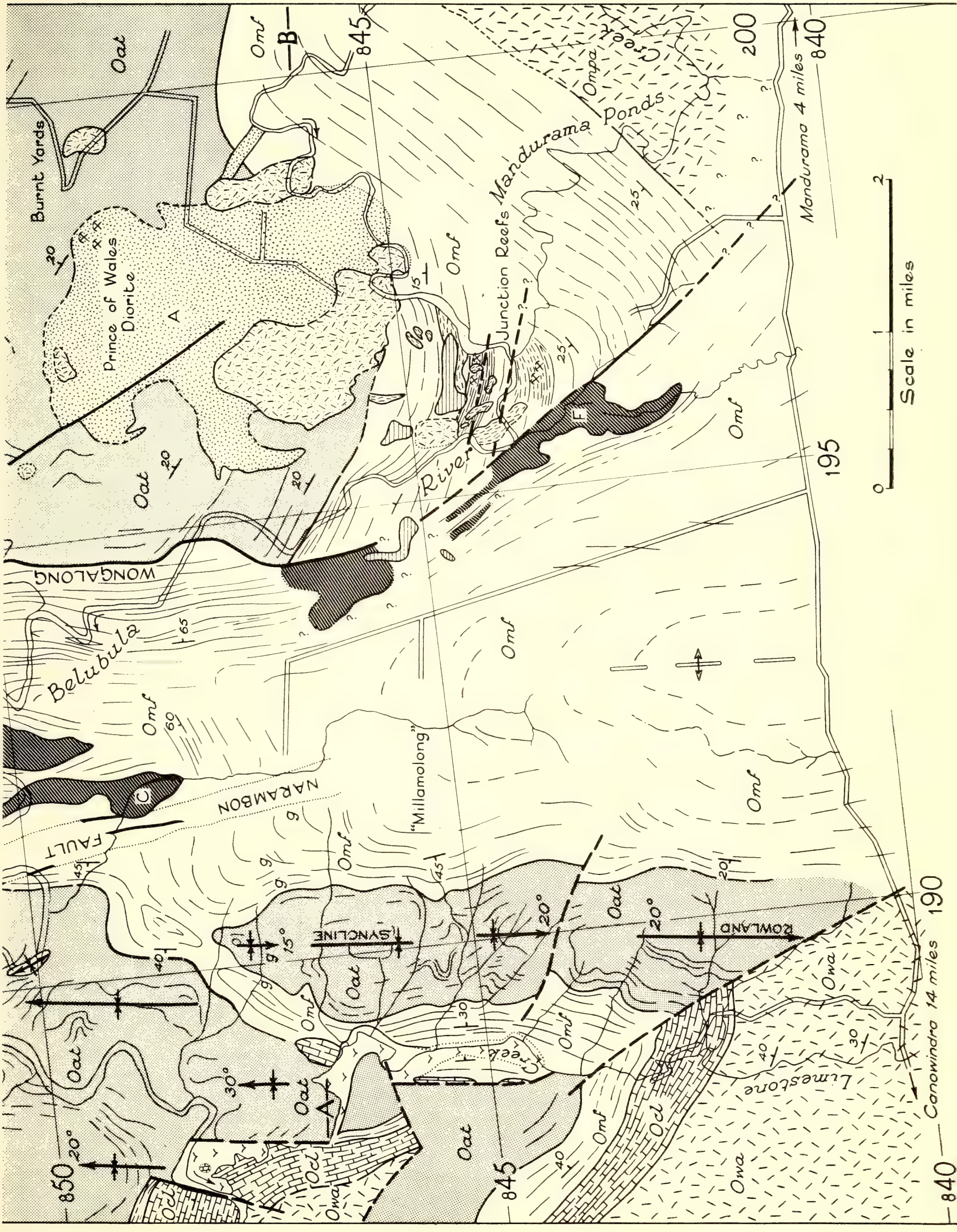


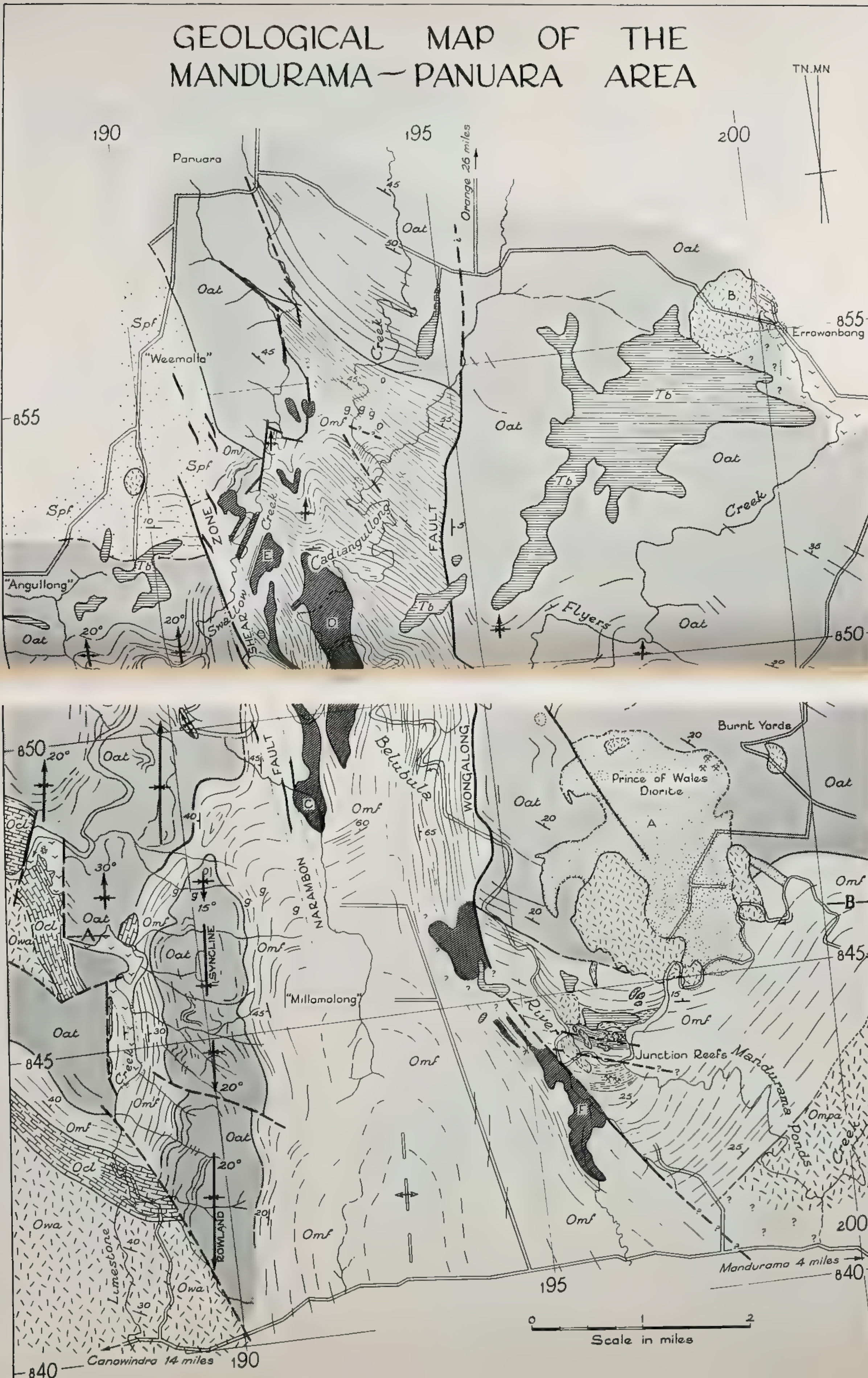
Section A-B
Narambon Fault
A
Omf
Oat
Oat
Ocl
Owa
Omf
Owa
x 1000 ft
5
0
0
5
(a)
West
Suggested Environmental Distribution
8
7
6
5
Spf
(c)
10
(b)
ANGULLONG
TUFF
Oat
5
Ocl
Omf
MALONGULLI
Owa
0
(a)
? Terrestrial
Epineritic
Neritic
Neritic / Bathyal
volcanic breccia
greywacke suite, (volcanic)

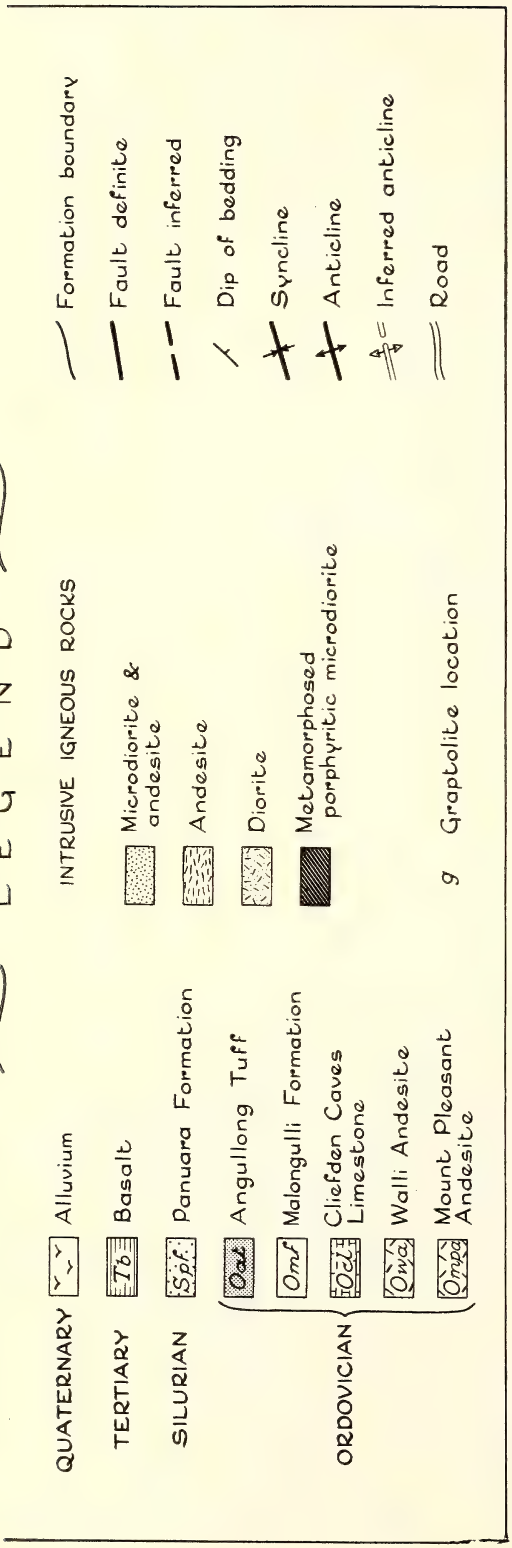

Wongalong Fault
B
Oat
Omf
Ompa
ground surface
East
Scale in miles
4
3
2
1
0
x1000ft
10
5
0
(d)
(e)
FORMATION
shale & siltstone
limestone
pillow lava
(b)
approximate environmental boundary


Section A-B
Narambon Fault
Wongalong Fault
A
B
Omf
Oat
Ol
Owa
Ompa
ground surface
5
x1000 ft
0
0
5
(a)
West
Suggested Environmental Distribution
East
Scale in miles
x1000ft
8
7
6
5
3
2
1
0
10
5
0
(b)
(c)
(d)
(e)
Spf
ANGULLONG
TUFF
Oat
Omf
MALONGULLI
FORMATION
Ol
Owa
Ompa
?Terrestrial
Epineritic
Neritic
Neritic / Bathyal
volcanic breccia
greywacke suite, (volcanic)
shale & siltstone
limestone
pillow lava
approximate environmental boundary


GEOLOGICAL MAP OF THE
MANDURAMA — PANUARA AREA
TN. MN
Panuara
Errowanbang
Orange 26 miles
FAULT
SHEAR ZONE
"Weemalla"
"Angullong"
Cadiangullong Creek
Flyers Creek
Swallow
Creek
Oat
Tb
Omf
Om
Spf
B
D
E
190
195
200
855
850


Burnt Yards
Prince of Wales
Diorite
Oat
Omf
B
845
200
840
Ompa
Creek
Mandurama Ponds
Junction Reefs
Mandurama 4 miles
Scale in miles
0
1
2
River
F
195
WONGALONG
Belubula
"Millamolong"
NARAMBON
FAULT
C
SYNCLINE
ROWLAND
190
Owa
Od
Limestone
Canowindra 14 miles
850
845
840


GEOLOGICAL MAP OF THE MANDURAMA — PANUARA AREA
TN. MN
190
195
200
Panuara
Orange 26 miles
Oat
Spf
"Weemolla"
Omf
Creek
Tb
B
Errowanbang
855
850
845
840
FAULT
Cadiangullong
ZONE
SHEAR
Swallow
E
D
"Angullong"
Flyers
Burnt Yards
Prince of Wales Diorite
A
Ocl
Owa
SYNCLINE
NARAMBON
Belubula
WONGALONG
C
"Millamolong"
River
Junction Reefs
Mandurama Ponds
Ompa
F
Limestone
ROWLAND
Mandurama 4 miles
Canowindra 14 miles
Scale in miles
0
1
2



intermontane basins characterised by carbonates and calcilutites, and by rich marine fauna. The Malongulli Formation represents deposition during one such quiet period which began after the extrusion of the Walli and Mount Pleasant Andesites, and ended with the vulcanism which marks the base of the Angullong Tuff. The Hill End Trough began rapid subsidence in Upper Ordovician time (during deposition of the Angullong Tuff), the subsidence being accompanied by violent eruptions of intermediate to basic lavas, volcanic breccias, and tuff, with corresponding thick accumulations of labile conglomerate, labile greywackes and lavas.

The volcanic arc was violently active until the end of the Middle Devonian. The Tabberabberan Orogeny marks the stabilisation of this zone and marks the transition from flysch to molasse sedimentation.

Acknowledgements

I wish to thank Professor C. E. Marshall for making the laboratory facilities available, Dr. T. G. Vallance, Dr. A. A. Day, Dr. G. H. Packham, Dr. I. M. Threadgold, Dr. T. B. H. Jenkins, Dr. B. E. Hobbs, Mr. R. H. Vernon, and Messrs. W. R. Ryall, H. T. Moors, A. Raam, for much appreciated discussion concerning the manuscript. I wish to thank Miss K. Parker for gratuitously typing the manuscript, and Miss J. Forsyth for drafting the map, viz Fig. 6.

I wish also to acknowledge the hospitality of the residents of the district, and in particular I wish to thank Mr. and Mrs. J. Warner of 'Weemalla' for providing unmatched accommodation and hospitality during the field study.

Fossil Locations

CO.1/40. Grid reference (937546), within the Malongulli Formation, approximately 2,000 feet stratigraphically below the base of the Angullong Tuff. The location is on the east bank of Cadiangullong Creek, about 15 feet south of the side gully.

Ptilograptus
Loganograptus logani
Tetragraptus, horizontal form
Didymograptus nodosus (identified by Dr. G. H. Packham)
Isograptus caduceus, several subspecies
Cryptograptus ? tricornis
Glossograptus acanthus
Glossograptus crudus

Glossograptus hicksii
Glyptograptus resembling *austrodentatus*
Trigonograptus ensiformis
trilobite fragments, sowerbyella, and lingula brachiopods.

This assemblage indicates a Darriwilian (D2 to D3) age.

CO.1/41. Grid reference (937546). The location is on the east bank of Cadiangullong Creek, 100 feet upstream of location CO.1/40.

Tetragraptus, horizontal form
Isograptus caduceus
Amplexograptus, resembling *differtus* and *confertus*
Trigonograptus ensiformis
Thysanograptus etheridgei

Darriwilian age.

CO.1/42. Grid reference (937546), in the gully on the east bank of Cadiangullong Creek, approximately 50 feet stratigraphically above CO.1/41, but to the east.

Callograptus
Dictyonema, fragmental
Tetragraptus, horizontal form
Didymograptus nodosus
Isograptus caduceus, narrow variety
Isograptus forcipiformis
Glossograptus acanthus
? *Amplexograptus*

Darriwilian age.

CO.1/43. Grid reference (936547). Located on the west slope of Cadiangullong Creek at approximately the same stratigraphic level as CO.1/40.

Didymograptus nodosus
Glyptograptus resembling *austrodentatus* except for the extreme length which may reach 7 cms. or more.

CO.1/44. Located in the Panuara Formation, at the top end of Cobblers Creek, about 50 yards west of the Panuara–Angullong Road, west of ' Weemalla ' mail box, grid reference (904559).

Monograptus tumescens
Monograptus tumescens var minor.

Melbournian age.

CO.1/46. Grid reference (908473). Located in the Malongulli Formation, approximately 50 feet below the base of the Angullong Tuff in the Rowland Syncline.

Climacograptus tubuliferous (identified by H. T. Moors)
Glyptograptus teretiusculus

Also present is a genus which resembles *Petalograptus altissimus* but also shows some affinities with *Paracardiograptus* (Mu), particularly in the gently curved thecae, see Mu and Lee (1958). The proximal ends available lacked the necessary detail for identification. *Paracardiograptus* in Western Chekiang appears in the *Cardiograptus* subzone which is closer to the probable Eastonian age of the above assemblage, based on the range of *Climacograptus tubuliferous*, than the British range of *Petalograptus* which occurs much higher, in the upper part of the Llandovery or Lower Silurian.

CO.1/47. Grid reference (900475). Located in the Malongulli Formation in the west limb of the Rowland Syncline.

Glyptograptus teretiusculus

This species has a range of Darriwilian D3 to Gisbornian.

CO.1/50. Grid reference (955554). Located in the Angullong Tuff at Rodds Creek, southeast of ' Oaky Creek ' homestead.

Tabulate corals including halysitids and favositids.

CO.1/51. Grid reference (908540). Located in the Panuara Formation in the gully north of the Narambon Fault, about 400 yards northeast of ' Narambon ' homestead.

Lichenaria, favositids, halysitids.

Silurian age.

Prince of Wales Diorite

Table I

Table I*a*

Average mode for the aphyric variety

5%	Quartz
30%–35%	Plagioclase An_{55} to An_{20} (zoned)
15%–20%	Orthoclase
5%	Biotite
10%–15%	Augite
20%–25%	Tremolite-actinolite
2%	Opaques.

Table I*b*

Average mode for the porphyritic varieties

Phenocrysts	
25%	Plagioclase An_{55} to An_{20}
10%	Augite
5%–10%	Tremolite-actinolite, replacing augite.
Groundmass	
30%	Plagioclase An_{25}
10%–20%	Tremolite-actinolite
2%	Biotite
10%	Opaques.

Minor Intrusive Bodies

Table I*c*

Phenocrysts	
15%	Plagioclase Albite
10%	Hornblende
5%–10%	Quartz
Groundmass	
50%	Felsite
2%	Biotite
10%	Chlorite, carbonate, prehnite
5%	Ilmenite, altered to leucoxene, and sphene
tr.	Opaques

Grid reference (918520).

Table I*d*

Phenocrysts	
30%	Plagioclase Albite
20%	Epidote after amphibole
Groundmass	
35%	Felsite
5%	Chlorite, carbonate
5%	Sphene
5%	Epidote

Grid reference (925510).

Table I*e*

Phenocrysts	
20%–30%	Plagioclase Albite
Groundmass	
40%–50%	Albite
5%	Quartz
10%–15%	Chlorite, prehnite
5%	Ilmenite altered to leucoxene, sphene
tr.	Apatite

Grid reference (958426).

Table I*f*

20%–25%	Plagioclase, albite An_0 to An_{05}
10%	Quartz
40%–55%	Orthoclase (perthite)
2%	Relic augite
10%	Tremolite-actinolite replacing augite
5%	Chlorite
5%	Prehnite, epidote
3%	Opaques.

Table I*g*

45%	Plagioclase, zoned andesite to oligoclase
10%–15%	Augite
5%	Orthoclase
10%–15%	Quartz
5%	Mica biotite, muscovite

Minor Intrusive Bodies (*Continued*)

5%–15%	Chlorite
2%	Apatite
1%	Epidote, prehnite, sphene
2%	Opaques.

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Precise Observations of Minor Planets at Sydney Observatory During 1963 and 1964

W. H. Robertson

The programme of precise observations of selected minor planets which was begun in 1955 is being continued and the results for 1963 and 1964 are given here. The methods of observation and reduction were described in the first paper (Robertson, 1958). All the plates were taken with the 9-inch camera by Taylor, Taylor and Hobson (scale 116″ to the millimetre). Four exposures were made on each plate. With the exception of the first three (613 to 618) the plates for 4 Vesta were taken with a coarse wire grating placed in front of the lens giving first order spectra which are 2·3 magnitudes fainter than the central image and displaced 0·32 mm. from it in an east-west direction. The spectra were measured for the planet and the central image for the stars.

In Table I are given the means for all four images for the separate groups of stars at the mean of the times. The differences between the results average $0^{s}\cdot025$ secδ in right ascension and $0\cdot''34$ in declination. This corresponds to probable errors for the mean of the two results from one plate of $0^{s}\cdot011$ sec δ and $0\cdot''14$. The result from the first two exposures was compared with that from the last two by adding the movement computed from the ephemeris. The means of the differences were $0^{s}\cdot010$ sec δ in right ascension and $0\cdot''12$ in declination. No correction has been applied for aberration, light time or parallax but the factors give the parallax correction when divided by the distance. The observers at the telescope were W. H. Robertson (R), K. P. Sims (S) and Harley Wood (W).

In accordance with the recommendation of Commission 20 of the International Astronomical Union, Table II gives for each observation the positions of the reference stars and the dependences. The columns headed "R.A." and "Dec." give the seconds of time and arc with proper motion correction applied to bring the catalogue position to the epoch of the plate. The column headed "Star" gives the number from the Yale Catalogue (Vols. 11, 12 I, 12 II, 13 I, 13 II, 14, 16, 17). The majority of the plates were measured by Miss W. Bellamy, Mrs. J. Brannigan, Miss J. Doust, Miss B. Frank and Miss E. Hardaker who have also assisted with the reductions.

Reference

Robertson, W. H., 1958. J. Roy. Soc. N.S.W. 92, 18. Sydney Observatory Papers No. 33.

Table I

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
		18 Melpomene 1963 U.T.									
561	April	18·68534	16	19	01·563	—06	21	19·20	—0·008	—4·03	R
562	April	18·68534	16	19	01·570	—06	21	18·98			
563	May	14·60377	15	59	47·200	—03	56	57·80	0·000	—4·35	R
564	May	14·60377	15	59	47·176	—03	56	57·91			
565	May	20·58018	15	53	55·512	—03	31	57·60	—0·009	—4·41	S
566	May	20·58018	15	53	55·480	—03	31	57·29			
567	June	17·50083	15	28	46·448	—02	55	39·27	+0·035	—4·49	W
568	June	17·50083	15	28	46·436	—02	55	38·99			
569	July	08·44087	15	19	53·636	—04	00	25·65	+0·046	—4·35	S
570	July	08·44087	15	19	53·622	—04	00	26·47			
571	July	22·38210	15	20	26·733	—05	16	46·51	—0·018	—4·17	R
572	July	22·38210	15	20	26·688	—05	16	46·57			

TABLE I—*continued*

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
		39 Laetitia 1963 U.T.									
573	April	18·71092	16	55	02·600	—08	29	32·46	—0·006	—3·74	R
574	April	18·71092	16	55	02·590	—08	29	32·62			
575	May	14·63170	16	42	35·731	—06	33	47·74	—0·005	—4·00	R
576	May	14·63170	16	42	35·764	—06	33	48·22			
577	May	20·60880	16	38	01·912	—06	12	29·94	—0·015	—4·05	S
578	May	20·60880	16	38	01·904	—06	12	30·22			
579	June	17·53079	16	15	06·024	—05	30	08·54	+0·033	—4·15	W
580	June	17·53079	16	15	06·048	—05	30	09·12			
581	July	22·41303	16	01	16·830	—07	06	34·80	—0·010	—3·93	R
582	July	22·41303	16	01	16·832	—07	06	34·90			
		1 Ceres 1964 U.T.									
583	April	28·75268	18	29	55·942	—22	56	06·97	+0·011	—1·64	W
584	April	28·75268	18	29	55·956	—22	56	06·09			
585	May	13·69898	18	28	03·450	—23	43	37·22	—0·027	—1·53	S
586	May	13·69898	18	28	03·460	—23	43	36·40			
587	May	18·69520	18	26	04·743	—24	01	41·08	+0·011	—1·48	W
588	May	18·69520	18	26	04·748	—24	01	40·88			
		1 Ceres 1964 U.T.									
589	June	01·64645	18	17	18·222	—24	55	35·23	—0·004	—1·34	R
590	June	01·64645	18	17	18·231	—24	55	35·54			
591	June	23·57972	17	57	04·285	—26	16	23·76	+0·021	—1·14	R
592	June	23·57972	17	57	04·307	—26	16	22·99			
593	June	29·57351	17	51	15·552	—26	34	46·38	+0·068	—1·11	S
594	June	29·57351	17	51	15·648	—26	34	46·42			
595	July	06·53483	17	44	53·964	—26	53	28·84	+0·017	—1·04	W
596	July	06·53483	17	44	53·988	—26	53	28·30			
597	July	16·49563	17	37	07·882	—27	15	28·64	—0·005	—0·98	R
598	July	16·49563	17	37	07·850	—27	15	28·84			
599	July	27·47051	17	31	07·753	—27	34	29·58	+0·026	—0·94	S
600	July	27·47051	17	31	07·729	—27	34	30·08			
601	August	05·43976	17	28	32·456	—27	47	13·88	+0·011	—0·90	S
602	August	05·43976	17	28	32·430	—27	47	14·16			
603	August	10·42264	17	28	02·894	—27	53	35·96	0·000	—0·89	R
604	August	10·42264	17	28	02·921	—27	53	36·10			
605	August	12·42547	17	28	02·463	—27	56	03·05	+0·029	—0·88	R
606	August	12·42547	17	28	02·452	—27	56	03·74			
607	August	20·40740	17	29	04·476	—28	05	24·58	+0·040	—0·86	S
608	August	20·40740	17	29	04·464	—28	05	23·36			
609	Sept.	03·37312	17	34	42·220	—28	20	16·03	+0·040	—0·83	S
610	Sept.	03·37312	17	34	42·190	—28	20	15·56			
611	Sept.	09·35699	17	38	28·606	—28	25	58·61	+0·032	—0·81	R
612	Sept.	09·35699	17	38	28·602	—28	25	58·82			
		4 Vesta 1964 U.T.									
613	June	23·78256	23	12	18·372	—11	00	17·62	—0·029	—3·40	R
614	June	23·78256	23	12	18·375	—11	00	18·00			
615	July	01·77356	23	17	30·582	—11	06	45·78	0·000	—3·38	S
616	July	01·77356	23	17	30·575	—11	06	46·25			
617	July	07·76898	23	20	23·156	—11	19	24·38	+0·030	—3·36	W
618	July	07·76898	23	20	23·091	—11	19	24·72			
619	July	13·75122	23	22	17·830	—11	38	59·36	+0·022	—3·31	R
620	July	13·75122	23	22	17·784	—11	38	59·04			
621	July	20·73124	23	23	15·191	—12	10	35·36	+0·017	—3·23	S
622	July	20·73124	23	23	15·232	—12	10	35·38			
623	July	29·69802	23	22	23·720	—13	04	13·77	—0·008	—3·11	W
624	July	29·69802	23	22	23·760	—13	04	13·71			
625	August	04·67970	23	20	30·160	—13	47	08·84	—0·010	—3·00	R
626	August	04·67970	23	20	30·158	—13	47	08·86			

TABLE I—*continued*

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
627	August	11·66596	23	17	00·747	—14	42	41·99	+0·014	—2·87	S
628	August	11·66596	23	17	00·780	—14	42	42·18			
629	August	20·61194	23	10	49·254	—15	57	59·76	—0·066	—2·70	S
630	August	20·61194	23	10	49·186	—15	58	00·15			
631	Sept.	08·56669	22	54	06·701	—18	23	07·78	—0·008	—2·33	R
632	Sept.	08·56669	22	54	06·711	—18	23	08·00			
633	Sept.	15·54300	22	48	00·228	—19	02	00·48	—0·009	—2·24	R
634	Sept.	15·54300	22	48	00·248	—19	01	59·90			
635	Sept.	24·52930	22	41	11·766	—19	35	33·45	+0·042	—2·16	S
636	Sept.	24·52930	22	41	11·770	—19	35	32·57			
637	Sept.	29·50061	22	38	09·784	—19	45	43·34	0·000	—2·13	R
638	Sept.	29·50061	22	38	09·726	—19	45	43·66			
639	Oct.	08·48532	22	34	18·734	—19	49	07·70	+0·039	—2·12	S
640	Oct.	08·48532	22	34	18·772	—19	49	07·74			
641	Oct.	22·43285	22	32	55·061	—19	19	43·59	—0·005	—2·21	R
642	Oct.	22·43285	22	32	55·084	—19	19	43·81			
643	Oct.	28·42111	22	34	00·006	—18	56	03·40	+0·008	—2·25	S
644	Oct.	28·42111	22	34	00·034	—18	56	03·06			
		7 Iris 1964 U.T.									
645	March	16·71850	14	43	24·978	—21	45	15·60	+0·028	—1·81	W
646	March	16·71850	14	43	24·988	—21	45	16·00			
647	March	23·68733	14	40	37·001	—21	38	05·10	—0·004	—1·83	R
648	March	23·68733	14	40	37·025	—21	38	05·22			
649	April	02·65271	14	34	35·887	—21	15	30·14	—0·015	—1·88	S
650	April	02·65271	14	34	35·910	—21	15	30·22			
651	April	07·64620	14	30	48·150	—20	58	39·60	+0·017	—1·93	W
652	April	07·64620	14	30	48·137	—20	58	39·79			
653	April	13·62306	14	25	43·254	—20	33	50·38	+0·006	—1·99	R
654	April	13·62306	14	25	43·266	—20	33	50·38			
655	April	23·59645	14	16	25·424	—19	42	35·86	+0·030	—2·14	S
656	April	23·59645	14	16	25·406	—19	42	35·80			
657	April	30·57964	14	09	44·853	—19	01	20·94	+0·052	—2·23	W
658	April	30·57964	14	09	44·812	—19	01	21·42			
659	May	07·54288	14	03	19·620	—18	17	51·42	+0·009	—2·32	R
660	May	07·54288	14	03	19·680	—18	17	51·26			
661	May	13·51769	13	58	14·491	—17	40	10·87	—0·008	—2·42	S
662	May	13·51769	13	58	14·524	—17	40	10·86			
663	May	19·50620	13	53	42·928	—17	03	34·01	+0·017	—2·50	W
664	May	19·50620	13	53	42·875	—17	03	33·36			
665	May	28·46565	13	48	16·760	—16	13	26·38	—0·021	—2·63	R
666	May	28·46565	13	48	16·788	—16	13	26·84			
667	June	01·47086	13	46	25·563	—15	53	33·39	+0·034	—2·68	S
668	June	01·47086	13	46	25·561	—15	53	33·02			
669	June	16·41544	13	42	52·111	—14	56	47·30	—0·004	—2·81	R
670	June	16·41544	13	42	52·098	—14	56	47·44			
671	July	06·36695	13	46	07·879	—14	28	05·15	+0·008	—2·88	R
672	July	06·36695	13	46	07·904	—14	28	05·82			

Table II

No.	Star	Depend.	R.A.	Dec.
561	5631	0·348535	08·349	23·56
	5676	0·281006	15·639	16·85
	5689	0·370460	34·002	10·44
562	5659	0·339322	44·803	25·75
	5694	0·230320	44·581	20·04
	5646	0·430358	37·319	42·18
563	5533	0·247544	59·136	16·16
	5550	0·348056	29·356	12·14
	5566	0·404400	22·189	34·38
564	5541	0·387559	26·819	02·94
	5557	0·414760	33·928	55·94
	5571	0·197681	44·247	48·11
565	5514	0·246458	01·818	25·82
	5525	0·542316	26·249	42·59
	5533	0·211226	59·136	16·16
566	5511	0·324491	39·336	34·78
	5531	0·483180	23·250	57·09
	5541	0·192329	26·819	02·94
567	5398	0·249288	44·892	19·76
	5412	0·444343	54·709	07·29
	5419	0·306369	02·176	14·03
568	5394	0·368814	23·796	52·30
	5399	0·236338	02·456	47·74
	5434	0·394848	33·729	04·91
569	5353	0·397420	45·406	42·57
	5373	0·352500	08·029	18·88
	5385	0·250079	07·895	46·70
570	5354	0·308307	48·536	08·39
	5371	0·287463	38·928	05·21
	5376	0·404230	42·732	22·04
571	5365	0·279424	54·170	50·62
	5369	0·456096	34·774	50·86
	5378	0·264480	50·670	25·92
572	5351	0·228134	05·506	18·37
	5376	0·537033	42·738	22·03
	5377	0·234832	46·508	13·94
573	5802	0·391560	03·747	21·88
	5824	0·446737	48·963	54·01
	5834	0·161703	46·599	44·18
574	5818	0·545149	32·935	28·06
	5819	0·181263	48·495	02·94
	5822	0·273588	11·044	43·10
575	5768	0·287014	25·807	28·77
	5782	0·409896	28·973	12·82
	5739	0·303090	02·393	40·95
576	5770	0·242354	47·962	24·64
	5778	0·394268	19·133	29·79
	5784	0·363378	45·678	04·36
577	5713	0·461428	39·882	56·35
	5733	0·178241	46·729	44·17
	5767	0·360331	12·679	40·86
578	5760	0·194840	14·745	49·60
	5719	0·519972	21·435	01·60
	5727	0·285188	47·934	23·63
579	5614	0·284582	07·260	47·59
	5617	0·365472	05·413	24·95
	5646	0·349945	37·319	42·19
580	5618	0·333319	04·370	37·51
	5622	0·424064	21·465	02·09
	5639	0·242617	48·484	06·64
581	5565	0·263546	11·738	48·60
	5583	0·408502	31·748	55·10
	5599	0·327952	15·092	53·17
582	5566	0·394709	10·990	09·36
	5587	0·302812	33·171	23·56
	5609	0·302479	21·123	03·50

No.	Star	Depend.	R.A.	Dec.
583	12833	0·393972	18·083	06·78
	12857	0·330118	44·590	30·49
	12901	0·275910	29·258	52·12
584	12817	0·305524	40·634	03·95
	12882	0·515288	06·225	48·01
	12893	0·179188	07·250	14·33
585	12812	0·401846	28·886	11·87
	12833	0·379492	18·083	06·78
	12871	0·218662	32·014	47·24
586	12797	0·237698	05·177	55·84
	12808	0·426162	12·353	13·97
	12901	0·336139	29·259	52·12
587	12751	0·301150	26·859	47·36
	12824	0·428658	26·885	08·59
	12847	0·270192	03·523	09·33
588	12785	0·308240	17·357	33·32
	12808	0·470998	12·353	13·97
	12833	0·220762	18·083	06·78
589	12642	0·309514	52·864	53·29
	12705	0·321392	24·777	05·55
	12723	0·369094	12·800	27·57
590	12635	0·378195	37·313	14·72
	12725	0·312489	16·496	59·17
	12730	0·309316	48·295	51·62
591	12306	0·297864	20·339	18·30
	12309	0·288936	42·530	29·94
	12369	0·413200	15·938	08·11
592	12280	0·318210	16·953	57·69
	12326	0·325256	49·327	36·84
	12402	0·356534	41·216	33·46
593	11383	0·272690	03·817	55·15
	12256	0·420234	11·928	13·16
	12280	0·307077	16·952	57·69
594	12203	0·330546	58·064	49·45
	12227	0·225400	49·064	40·84
	12309	0·444053	42·531	29·94
595	12161	0·294550	18·807	55·82
	12225	0·297430	33·646	47·87
	11279	0·408021	22·482	14·43
596	11222	0·313076	41·065	17·36
	12163	0·290948	37·162	13·05
	12241	0·395977	56·688	34·83
597	11157	0·282036	56·581	08·58
	11196	0·308820	36·886	18·51
	12122	0·409144	57·808	18·70
598	11170	0·223273	02·886	06·83
	11229	0·321429	12·685	11·61
	12105	0·455298	58·393	34·82
599	11073	0·304314	25·956	55·99
	11136	0·430860	01·040	17·36
	11157	0·264826	56·581	08·58
600	11097	0·430934	47·111	57·63
	11170	0·208796	02·886	06·83
	12078	0·360270	39·164	25·96
601	11037	0·239062	39·961	46·28
	11073	0·374020	25·956	55·99
	11136	0·386918	01·040	17·36
602	12039	0·355332	42·886	22·95
	11098	0·492014	55·075	58·08
	11157	0·152654	56·581	08·58
603	11037	0·375544	39·960	46·28
	11073	0·263126	25·956	55·99
	11136	0·361329	01·040	17·36
604	11036	0·485078	36·298	03·14
	11170	0·307852	02·886	06·83
	12039	0·207070	42·886	22·95

TABLE II—*continued*

No.	Star	Depend.	R.A.	Dec.	No.	Star	Depend.	R.A.	Dec.
605	11036	0·357081	36·298	03·14	627	8614	0·323662	52·358	57·67
	11073	0·289980	25·956	55·99		8618	0·380040	41·399	38·79
	11136	0·352939	01·040	17·36		8648	0·296297	03·031	59·40
606	11037	0·348352	39·960	46·28	628	8624	0·411920	32·674	21·83
	11098	0·187514	55·075	58·06		8625	0·260528	52·658	49·44
	11114	0·464134	12·473	07·17		8630	0·327552	42·597	10·19
607	11037	0·278705	39·959	46·28	629	8579	0·342594	37·321	20·66
	11114	0·447774	12·474	07·18		8589	0·375038	24·714	50·24
	11132	0·273521	43·446	55·51		8610	0·282368	01·730	05·83
608	11043	0·308539	17·036	06·73	630	8576	0·400132	31·854	09·59
	11073	0·359078	25·956	55·99		8599	0·190440	15·365	42·08
	11161	0·332383	21·442	58·17		8600	0·409427	22·968	58·44
609	11132	0·378674	43·449	55·51	631	9648	0·374056	11·179	41·05
	11157	0·324511	56·582	08·58		9653	0·262272	24·916	29·21
	11215	0·296815	20·105	31·17		9688	0·363672	04·224	56·65
610	11098	0·304018	55·074	58·08	632	9646	0·333553	37·704	51·50
	11178	0·394725	02·088	54·45		9673	0·398395	23·192	26·60
	11212	0·301257	47·076	05·89		9680	0·268052	33·267	39·32
611	11170	0·343750	02·887	06·83	633	9618	0·391804	52·053	38·20
	11212	0·330676	47·076	05·89		9638	0·245196	06·099	08·78
	11250	0·325574	47·615	11·32		9646	0·363000	37·704	51·50
612	11183	0·253604	18·644	00·52	634	9623	0·440378	30·744	31·87
	11196	0·500831	36·887	18·51		9635	0·253212	12·720	06·05
	11270	0·245565	27·476	15·88		9653	0·306410	24·916	29·21
613	8117	0·325699	20·717	17·65	635	9581	0·264499	24·690	13·79
	8151	0·274892	51·715	61·94		9624	0·375896	38·325	51·99
	8157	0·399409	17·270	13·28		9586	0·359605	20·706	57·75
614	8135	0·474442	05·371	26·63	636	9576	0·287913	58·320	05·85
	8142	0·323324	44·445	17·08		9603	0·419565	11·998	52·79
	8153	0·202235	28·162	38·62		9611	0·292522	55·868	29·62
615	8157	0·320436	17·270	13·27	637	9576	0·376900	58·249	07·18
	8167	0·460834	16·766	22·56		9581	0·357064	24·690	13·79
	8170	0·218730	08·198	08·18		9593	0·266036	51·543	41·61
616	8151	0·301192	51·715	61·95	638	9568	0·312091	13·698	15·26
	8160	0·231210	17·244	24·10		9602	0·402534	55·458	28·06
	8176	0·467598	27·946	28·30		9572	0·285375	02·919	24·55
617	8160	0·162434	17·244	24·10	639	9544	0·391580	25·491	14·00
	8167	0·500150	16·766	22·56		9568	0·279230	13·698	15·26
	8190	0·337416	29·308	28·60		9576	0·329190	58·249	07·18
618	8157	0·259918	17·272	13·27	640	9549	0·365479	59·256	05·67
	8171	0·287416	15·271	23·51		9581	0·281505	24·690	13·79
	8183	0·452666	00·649	33·22		9565	0·353016	15·121	46·76
619	8171	0·326676	15·271	23·51	641	9549	0·445695	59·256	05·66
	8176	0·423162	27·950	28·29		9550	0·326266	59·771	32·37
	8204	0·250162	20·898	13·27		9572	0·228040	02·919	24·55
620	8160	0·256243	17·244	24·10	642	9544	0·524179	25·438	13·32
	8182	0·479436	43·594	30·32		9552	0·254154	27·662	31·28
	8191	0·264321	31·388	14·97		9576	0·221667	58·321	05·84
621	8171	0·336718	15·272	23·51	643	9546	0·271188	42·094	39·74
	8182	0·379441	43·594	30·32		9562	0·504704	54·986	50·02
	8196	0·283842	21·985	07·55		9576	0·224108	58·322	05·84
622	8175	0·319878	55·613	10·67	644	9544	0·332245	25·438	13·32
	8176	0·255540	27·952	28·29		9550	0·361820	59·771	32·37
	8197	0·424582	26·225	59·44		9584	0·305935	09·689	24·07
623	8171	0·291126	15·272	23·51	645	6129	0·440260	44·217	20·32
	8191	0·306490	31·388	14·97		6141	0·309546	30·466	01·04
	8654	0·402383	16·954	50·82		6153	0·250194	15·746	59·17
624	8168	0·312117	37·313	14·19	646	6124	0·324998	43·684	50·89
	8190	0·331462	29·310	28·60		6158	0·380342	05·925	45·19
	8655	0·356421	48·666	25·21		10595	0·294660	38·968	30·91
625	8636	0·285357	56·662	23·84	647	6093	0·252481	59·675	33·44
	8655	0·297258	48·667	25·21		6124	0·417203	43·684	50·89
	8175	0·417385	55·614	10·67		6145	0·330316	00·360	50·15
626	8168	0·224434	37·313	14·19	648	10572	0·276440	35·879	49·56
	8640	0·423070	01·157	54·01		6118	0·503346	44·408	53·39
	8654	0·352496	16·954	50·82		6144	0·220214	54·536	33·07

TABLE II—*continued*

No.	Star	Depend.	R.A.	Dec.
649	6066	0·385044	45·642	13·63
	6107	0·302211	34·480	02·15
	6108	0·312746	41·775	13·37
650	6073	0·442580	04·951	16·57
	6118	0·278696	44·408	53·39
	6090	0·278724	59·757	34·32
651	6052	0·313954	29·068	10·41
	6062	0·315824	51·020	56·12
	6092	0·370222	17·598	54·11
652	6050	0·486394	59·539	25·68
	6089	0·338008	54·677	33·00
	6083	0·175598	29·415	15·65
653	6021	0·363988	09·831	55·25
	6052	0·389477	29·069	10·41
	6059	0·246535	11·104	08·66
654	6025	0·331616	57·049	22·48
	6066	0·336716	45·642	13·63
	6034	0·331667	23·927	15·51
655	5976	0·358294	31·341	24·39
	5982	0·380350	19·286	59·33
	6008	0·261356	37·282	49·21
656	5983	0·412610	21·036	27·81
	5985	0·391202	39·245	54·91
	6007	0·196188	13·220	28·41
657	5947	0·353042	26·363	23·61
	5951	0·341652	54·872	47·52
	5984	0·305306	36·548	00·00
658	5941	0·403667	31·351	44·89
	5967	0·194898	08·742	11·28
	5971	0·401434	50·950	20·85
659	5252	0·391539	28·531	25·55
	5282	0·302702	47·643	12·86
	5285	0·305760	31·355	44·92
660	5246	0·340014	06·928	09·18
	5290	0·214459	48·459	20·08
	5933	0·445527	23·797	48·75
661	5232	0·232156	28·239	01·47
	5233	0·293770	29·641	25·80
	5255	0·474074	17·975	24·93
662	5236	0·237775	12·827	14·35
	5244	0·538307	11·052	10·67
	5254	0·223918	32·148	14·43
663	5216	0·224696	46·447	03·60
	5224	0·485041	07·247	26·67
	5236	0·290263	12·827	14·35
664	5217	0·289978	04·325	19·51
	5218	0·385722	21·365	58·78
	5239	0·324300	48·676	46·99
665	5191	0·315439	16·094	57·78
	5200	0·397229	19·508	45·27
	5220	0·287332	53·969	58·34
666	5185	0·362944	33·225	35·44
	5202	0·263002	02·271	20·72
	5213	0·374054	21·006	25·74
667	5182	0·397413	57·605	10·97
	5185	0·291532	33·225	35·44
	5213	0·311055	21·006	25·74
668	5165	0·253937	05·079	57·29
	5200	0·346268	19·509	45·27
	5202	0·399795	02·271	20·72
669	5158	0·433378	03·887	24·28
	5188	0·301507	47·717	13·98
	5191	0·265115	16·095	57·78
670	5165	0·325186	05·079	57·29
	5168	0·428142	40·643	35·19
	5199	0·246672	16·576	52·93
671	5182	0·287214	57·605	10·96
	5204	0·298250	35·701	39·92
	4893	0·414536	08·901	51·37
672	5168	0·382890	40·643	35·19
	5202	0·222848	02·271	20·72
	4909	0·394262	48·854	51·31

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